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HERMANN CARL VOGEL

By EDWIN B. FROST

It seems more fitting at this time to record the eminent services to science and the principal features of the life of this distinguished astrophysicist, rather than to seek appropriate words in which to deplore his loss, keenly as we feel it.

His place will be filled—no one man is any longer indispensable in the affairs of any properly regulated institution—and the splendid research observatory which he did so much to establish will continue its work, doubtless with little departure from the course which he had carefully laid out for it. But his pioneer researches, and his administrative achievements, opening an opportunity for many other significant investigations by his assistants and successors, have a permanent place in science. Their importance will later be even better appreciated than now, in the improved perspective which time alone can furnish.

Hermann Carl Vogel was born at Leipsic on April 3, 1842. As one of the youngest sons in a large family, in which high intellectual ideals prevailed, rather than considerations of material prosperity, his destiny was to be largely in his own hands. His father, Carl Cristoph Vogel, was a well-known educator, with practical tendencies, and superintendent of the schools of Leipsic. He was the author of several books on educational subjects and was the founder of the *Realschulen* of Leipsic, which afforded opportunity for a better preparation in prac-

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tical and scientific lines for the subsequent university course than did the *Gymnasia.*

The intellectual inheritance and early training of this family is further evidenced by the careers of others of its members. An older brother of Hermann, Eduard, after completing a brilliant course at the university, was called to London to take part in the work of Mr. Bishop's private observatory, then in charge of Dr. Hind. Diverted from astronomy by his interest in exploration and the natural sciences, he entered in 1850 upon extensive and ultimately fatal travels in Africa, under the auspices of the Royal Geographical Society. A sister was well known in recent German literature under the pseudonym of Elise Polko, writing principally on topics connected with music.

The natural tendencies of Hermann Vogel were toward practical things: his early intention was to become a locomotive builder. This interest and ability in mechanical matters was of much advantage in his subsequent career, greatly assisting him in designing new instruments and apparatus. While at the Polytechnic in Dresden both of his parents died, and his lack of both health and means compelled him to forego his ambitions for a profession in technology. At this juncture relief came in the person of a Russian prince desiring instruction in photography, which Vogel later assisted in making such a powerful auxiliary of the new astronomy. With the assistance of his patron he was able to get a fresh start, and he returned to Leipsic. Here, Carl Bruhns, himself a self-made man, recognizing young Vogel's ability, gave him a position in the newly established observatory at the princely salary of $150 per year. The columns of the *Astronomische Nachrichten* from 1866 onward attest to the activity of the young assistant in his new position, his observations being chiefly on asteroids, comets, and nebulae.

At this period Zöllner was by his masterly researches opening the way for astrophysics, and his influence is doubtless in a measure responsible for Vogel's subsequent interest in this branch. Vogel was meanwhile pursuing his studies in the university, although his lack of funds did not allow him to hear many of the courses of lectures. In 1868 he took his doctor's degree at Jena with a thesis on the micrometrical determination of the positions of nebulae and star clusters, with a historical sketch of the observations of nebulae.

In 1870 he was appointed director of the newly established and finely equipped private observatory of Chamberlain von Bülow at Bothkamp in Holstein, not far from Kiel. Here in the next four years he planned and executed many important researches in astrophysics, which are recorded in the first two volumes of publications of that observatory. A large part of the programme was given to spectroscopic observations of sun, stars, nebulae, planets, comets, aurora, and lightning, including line-of-sight measurements on sun and stars. Provision was also made for solar photography, the dry-plate process of Fothergill, as modified by Gordon, being successfully employed (1871).

The work at Bothkamp was done with the assistance of Dr. O. Lohse, who was subsequently one of the first observers appointed at the Potsdam Observatory.

It is interesting to note that the admirable style of publication later characteristic of the Potsdam *Publicationen* was introduced by Vogel in the volumes recording the observations made at Bothkamp.

The work so effectively commenced at the private observatory was not long to be continued, for the call soon came to the young man to enter the service of the Prussian state, and assist in developing plans for an astrophysical observatory to be established in the vicinity of Berlin. The brilliant researches of Kirchhoff had aroused the desire for such an institution, which at first was planned to be rather a *Sonnenwarte* than a *Sternwarte*. The interest of the crown prince, later Kaiser Friedrich, materially assisted toward the realization of the hopes of the scientific men principally active in the new enterprise. The minister of education in 1873 appointed a special committee, with Professor E. du Bois-Reymond as chairman, and the work of preparing plans for the institution was undertaken by a subcommittee consisting of Professors Auwers, Förster, and Kirchhoff. In 1874 appointments were made of two observers, Professors Vogel and Spörer, the latter having become well known for his faithful observations of the sun while a teacher in the *Gymnasium* at Anklam; and to them was assigned the duty of planning the initial instrumental equipment of the institution, the site for which had now been definitely located in the "Telegraphenberg" at Potsdam. In connection with these

duties Vogel made a visit to England, Scotland, and Ireland, ordering some of the instruments. Otherwise he traveled but little.

The first idea of having the new institute associated with the Observatory of Berlin was given up, and no provision was made for instruction. The observatory was not completed until 1879, but during these five years largely devoted to planning and executive duties, Vogel's observational activity was not suspended, and a number of his earlier pieces of work were published. Until 1882 the scientific and business administration of the institution was provisionally in the hands of a directorate consisting of the three gentlemen previously serving as a subcommittee. Vogel was then appointed director, a position he was to fill with eminent success for the next quarter of a century.

The equipment of the new institute was admirably adapted to its purposes, and fairly liberal appropriations were made for new apparatus; the principal telescopes (refractors of 13-, 8-, and 5-inches aperture) were, however, comparatively small. Activity was principally directed to celestial spectroscopy, celestial photometry, observations of the solar surface, both visual and photographic, direct planetary observations, and laboratory investigations of a physical nature. The director was fortunate in his choice of assistants, as the budget gradually permitted an enlargement of the staff; results were promptly published, in separate parts, as they were ready, in a clear and sufficiently detailed manner, which might well serve as a model for other institutions; and the premier position of the observatory in astrophysics was very soon established.

During Professor Vogel's administration the principal new developments were (1) the application of photography in stellar spectroscopy, particularly for determinations of velocities in the line of sight; (2) the construction of a new style of instrument (32-cm refractor) for stellar photography, and co-operation in the planning and subsequent work on the astrographic chart; (3) the construction and equipment of a large (80 cm) refractor particularly adapted for astrophysical research.

The first of these new departments opened the way for the modern investigations of the radial velocities of stars; it caused the evolution of the spectroscope into the spectrograph, and led to new types of

construction of that effective instrument both at Potsdam and elsewhere; it carried much farther the pioneer work of Huggins on photographic spectra of stars. It also led (1889) to the spectrographic demonstration of the correctness of the eclipse theory of the light-variation of *Algol*, which Vogel had unsuccessfully attempted with a visual spectroscope in 1875; and to the discovery of the existence of spectroscopic binary systems in which one component star was relatively dark (*Spica*, 1889). Vogel's name will perhaps be longest remembered for this discovery of spectroscopic binaries; and he will share in its credit with Professor E. C. Pickering, who was simultaneously interpreting in a similar manner the varying duplicity of lines in the objective-prism spectra of *Mizar* and *β Aurigae*.

By his use of metallic terminals (iron) as a source of the comparison spectrum, in addition to, or substitution for, the hydrogen tube generally employed, Vogel also opened the way for what is now the universal practice, although he seems not to have fully appreciated its advantage, and only employed the method in exceptional cases.

In 1892 he was able to publish (Bd. VII, Theil I) a catalogue of the radial velocities of 52 stars determined with a precision very superior to that of the visual measures then extant, which were hardly competent to give even the direction of motion of the stars—whether approach or recession; and in view of the extreme difficulty of such measures visually, this may be said without any discredit to the visual observers. In these spectrographic investigations, as in many others, Professor Vogel had the efficient collaboration of Dr. Scheiner.

With this list of stars the limit of the 12-inch (30 cm) Schröder refractor was practically reached for spectrographic observations, and for this work the director's desire grew keener for a larger telescope, comparable with those in use in foreign observatories. But the government's financial condition did not then permit the desired enlargement of the telescopic equipment.

Meanwhile the observatory undertook an active part in the preparations for the astrographic catalogue (but abstained from co-operating on the astrographic chart), and the photographic refractor of 32.5-cm (12.8 in.) aperture and 343-cm (145.7 in.) focal length was designed on a new principle and constructed by Repsold (optical parts by Steinheil). The pier was made of two riveted castings set at such

an angle that the upper casting pointed toward the pole,[1] permitting an unhindered motion of the instrument in right ascension (a point of great importance in long exposures) and combining the advantages of the so-called "English" and "German" types of mounting. The guiding telescope, rigidly attached within the same tube, is of aperture 23.5 cm and of the same focal length. This effective telescope was Vogel's favorite instrument in recent years and he designed in succession a number of spectrographs for it, after a provisional spectrograph had yielded useful results on *Nova Aurigae* in 1892.

In conjunction with Professor Wilsing he published in 1898 a valuable work of reconnaissance entitled *Untersuchungen über die Spectra von 528 Sternen* (from spectrograms taken with this telescope), dealing principally with stars of the first type and referring especially to the presence in them of helium. Professor Vogel's last published paper (constituting Part 1 of the fifteenth volume of the Potsdam Publications), issued shortly before his death, gives a detailed description of "Die zwei Doppelrefraktoren des Observatoriums," referring to this telescope and the great 80-cm refractor to which allusion will next be made.

It is doubtful if any large refractor has ever been constructed with a more thorough advance study of its adaptation to the purposes for which it was to be used than this great photographic telescope of 31.5-inches aperture. Extensive measurements were made at the observatory of the absorption of various kinds of glass for the different rays, and the size of the objective was determined in accordance with the data gained.[2] During the years of waiting for the necessary grant from the government, the details of the mechanical construction had been minutely worked out, so that contracts could be let quite promptly after imperial influence had led to the authorization of the instrument in 1895. Some features were novel, particularly in regard to the observing platform. The large object glass, when delivered, was subjected to more extensive and thorough tests, chiefly by Pro-

[1] It was long supposed by all concerned that this design was unique, but it subsequently appeared that a similar type of construction had been used at the Orwell Park Observatory, Ipswich, England, in 1874.

[2] H. C. Vogel, "The Absorption of Light as a Determining Factor in the Selection of the Size of the Objective for the Great Refractor of the Potsdam Observatory," *Astrophysical Journal*, **5**, 75–91, 1897.

fessor Hartmann, than has probably ever been the case previously. In his last paper Vogel gives an interesting account of these investigations, which must have given him much concern, and he candidly prints both the more favorable and the less favorable opinions of those charged with making trials of the performance of the lens. This somewhat extended reference to the construction of these telescopes is made here, because they absorbed no small part of the director's energies in recent years. He writes with a natural satisfaction that during his administration the instrumental equipment could thus be brought to a certain state of completeness, particularly as provision had also been made for securing reflecting telescopes of short focus, the advantages of which he fully appreciated.[1]

In his astrophysical researches and publications Professor Vogel's attitude was rationally conservative, but his mind was fully open to new developments. His point of view may be seen from *Newcomb-Engelmanns Populäre Astronomie*, two editions of which he edited. The last edition (1905), practically a new book, is now probably the best work on astronomy for the general reader. Of his contemporaries in pioneer astrophysical research, he seemed most in sympathy with Huggins, whose views were much like his own.

Vogel's published papers are very numerous. Aside from his many observations and orbital computations on asteroids and comets, he observed the satellites of *Jupiter* and *Uranus*, and triangulated the star cluster χ *Persei* while at Leipsic. He also made an extended study of the absorption in the solar atmosphere of the chemical rays, which was published in the *Berichte* of the Royal Saxon Academy for July 1, 1872. This research was extended to the yellow rays at Bothkamp, and was later (1876) greatly broadened so as to include many spectral regions, the observations being made with Vogel's modification of the Glan spectral photometer attached to the 9-inch refractor of the Berlin Observatory. It was published under the title "Spectralphotometrische Untersuchungen insbesondere zur Bestimmung der Absorption der die Sonne umgebenden Gashulle," in the *Monatsbericht* of the Berlin Academy for March, 1877 (41 pages). A brief set of spectral photometric observations of stars was also made at

[1] H. C. Vogel, "On Reflecting Telescopes of Relatively Short Focus," *Astrophysical Journal*, 23, 370–389, 1906.

Berlin, in conjunction with Dr. G. Müller, and later published by the same society.

An early investigation of much importance was *Untersuchungen über die Spectra der Planeten* (8vo, pp. 64, Leipsic, 1874), which was successfully submitted for a prize competition of the Copenhagen Academy of Sciences. These difficult visual observations were made at Bothkamp and include all the major planets, two asteroids, and the satellites of *Jupiter*. Twenty-one years later Vogel contributed to the Berlin Academy a paper upon the same subject: "Neuere Untersuchungen über die Spectra der Planeten." He comments on the fact that the observations of planetary spectra elsewhere published in the lapse of two decades had hardly done more than confirm his original results. This later discussion of the subject was based upon spectrograms taken for the most part with low dispersion, but not including the more refrangible regions of the spectrum. In the case of *Mars*, Vogel also made visual observations which appeared to confirm the earlier detection of atmospheric bands.

At Bothkamp he observed the Doppler effect at the opposite limbs of the sun, due to its rotation, and he made some observations of sunspot spectra and prominences; but in solar spectroscopy his principal piece of work was his *Untersuchungen über das Sonnenspectrum* (Part III of the first volume of the Potsdam Publications), in which, in conjunction with Professor Müller, he measured directly and on photographs the positions of some 2,600 lines between E and H, referred to Ångström's scale, and charted their positions in an atlas. The inaccuracy of Ångström's system being increasingly felt, new absolute determinations of the wave-lengths of 300 lines in the solar spectrum were later made by Müller and Kempf, and the 2,600 lines of Vogel's list were re-reduced to this system. These, with others measured by Müller and Kempf, making a total of 4,020 lines, constituted the Potsdam system of wave-lengths. But Rowland's photographic map, made with the concave grating, and his more extensive tables of wave-lengths, soon appeared and naturally superseded all others.

Vogel's field for personal research in the last twenty years was almost entirely in stellar spectroscopy. He had devoted much time to visual spectra at Bothkamp, and upon those observations he based his widely used classification of stellar spectra, first stated in *Astrono-*

mische Nachrichten, (**84**, 113, 1874). While adhering to Secchi's classification in a general way, Vogel enunciates distinctly that the guiding principle should be that of stellar development. He regards Secchi's third and fourth types as co-ordinate, distinguishing them as subdivisions of his third type. Vogel's system also makes an important addition, in differentiating three subdivisions of the first type, thus providing for stars of the *Orion* type and those having bright lines like γ *Cassiopeiae*. He also added a second subdivision to the second or solar type, II*b*, to include stars of the Wolf-Rayet type, having bright lines.

In a paper presented to the Berlin Academy in 1895, "Ueber das Vorkommen der Linien des Cleveitgasspectrums in den Sternspectren und über die Classification der Sterne vom ersten Spectraltypus," he avails himself of the data meanwhile gained by photography, and particularly after the discovery of helium, and the assignment to it of many significant lines previously unidentified, and he further differentiates the spectra of the first type. Subdivisions I*a*1 and I*a*2 and I*a*3 represent very marked differences in spectra. This restatement of his classification, particularly applying to the first type, is also given in the valuable paper on the spectra of 528 stars, already referred to (Bd. XII, Stück 1, *Publicationen*, Potsdam).

An earlier spectroscopic investigation, undertaken in conjunction with Dr. Müller, forms the third part of the third volume of the observatory's publications. It was the beginning of an attempt at a spectroscopic *Durchmusterung* of all the stars to magnitude 7.5 (inclusive) of the northern heavens. This paper (published in 1883) gives the results of a visual examination of over 4,000 such stars in the zone from $-1°$ to $+20°$ of declination. All honor to the skill and perseverance of the observers! Present-day workers who have dealt wholly with photographic spectra can scarcely appreciate the difficulties of such visual observations. This particular investigation was not extended to other zones, as the paramount advantages of photography for such surveys had meanwhile been demonstrated, principally at the Harvard Observatory by E. C. Pickering.

After his election to a seat in the Berlin Academy of Sciences in 1892, Vogel's papers chiefly appeared in the publications of that society, and were commonly translated for the *Astrophysical Journal*

from advance sheets at his request. These papers show the same careful study, and cautious, undogmatic expression, in regard to the qualitative part of an investigation as to its quantitative features, and they may well serve as models for younger men. Among these articles the following may be mentioned particularly:

"Ueber den neuen Stern im Fuhrmann," 1893, an especially thorough study of *Nova Aurigae* (60 pages).

"Ueber das Spectrum vom *β Lyrae*," 1894.

"Ueber das Spectrum von *Mira Ceti*," 1896.

"Ueber das Spectrum von *α Aquilae* und über die Bewegung des Sterns im Visionsradius," 1898.

"Ueber die in letzten Decennium in der Bestimmung der Sternbewegungen in der Gesichtslinie erreichten Fortschritte," 1900.

"Ueber das Spectrum der *Nova Persei*," 1901.

"Der spectroskopische Doppelstern *Mizar*," 1901.

"Ueber die Bewegung von *α Persei* in der Gesichtslinie," 1901.

"Ueber die Bewegung des Orionnebels im Visionsradius," 1902.

"Der spectroskopische Doppelstern *o Persei*," 1902.

"Untersuchungen über das spectroskopische Doppelsternsystem *β Aurigae*," 1904.

Appreciative references to Vogel's many inventions and devices in connection with spectroscopic apparatus will be found throughout Scheiner's *Spectralanalyse der Gestirne.*

Personally Professor Vogel was quiet and reserved; his health had been poor for a number of years, and it was only by the strictest care of himself that he was able to accomplish so much. He was a staunch friend, and always encouraged conscientious work of men younger than himself. Faithful to the memory of an early attachment he never married, but he took a warm interest in the *Familienglück* of his friends. He found great solace and relaxation in music, and both a large and small organ were at hand in his house. Sometimes, too, he went down to the famous old church in the crypt of which lies the body of Frederick the Great, and there played on the large organ with himself the only auditor. He had always been interested in entomology and had a fine collection, which he delighted in showing to interested friends. He frankly appreciated approbation, and was

the recipient of many honors, and of elections to membership in most of the leading learned societies of the world.

The condition of his health took a rather sudden change for the worse in the past summer, and on the evening of August 13, he passed away. Two days later he was borne for the last time to the great dome, where funeral services were appropriately held on August 17.

His achievements in research now become a part of scientific history; the memories of his personal qualities are a priceless possession of those privileged to be his friends.

CONTRIBUTION TO THE STUDY OF THE PHOTOSPHERE

By S. CHEVALIER

Although originated by M. Janssen at Meudon thirty years ago, the study of the granules of the photosphere has, as far as I know, made but little progress. But many questions may be raised concerning these granules. Besides those of a theoretical nature, which are still remote from our knowledge, there are many which do not transcend the mere statement of existing reality, and nevertheless they cannot be settled without difficulties. The dimension and form of the granules, their formation and transformation, their movements on the surface of the sun are some problems to which a good deal of attention has been paid at Zô-sè during the last two years. Though our investigation of the question is still far from being complete, the results already obtained seem to be worthy of publication.

Visual observations seem utterly powerless to solve such problems; photography therefore must be resorted to, if we are not reduced to the spectroscope alone. But though it is generally admitted that photography is not unsuited for the study of the photosphere, it must be confessed that photographs which can be used for this purpose are quite difficult to get, and when obtained, their interpretation is a matter of no little difficulty. The photographs made at Meudon by M. Janssen, though remarkably fine and clear, were crossed by a series of figures either circular or polygonal. While in the intervals between these figures the granules were quite clear and well shaped, inside of the figures they were distorted and tempest-tossed, so as almost to disappear. This appearance was considered by the best observers as due to a solar phenomenon, and was called by M. Janssen "photospheric *réseau*." Nevertheless, this net of figures has nothing to do with the photosphere. As far as I know this fact is now generally acknowledged. In the *Bulletin de la société astro-*

nomique de France for April 1906, M. Hansky, in a paper entitled: "Photographie de la granulation solaire," begins as follows:

> Les travaux de M. Janssen ont fait époque dans les études du soleil. Dans ce genre de recherches l'agitation de l'atmosphère trouble les images de telle façon que dans quelques endroits du disque solaire seulement, on obtient la photographie de la surface granulaire; le reste est flou et n'est que l'image des ondes de notre atmosphère qui passent au moment de la pose entre l'objectif et le soleil. Ainsi s'expliquent les différentes espèces du réseau photosphérique découvert par M. Janssen.
>
> Les conditions atmosphériques permettant d'obtenir la vraie forme de la granulation solaire sont si rares que, même dans la grande collection des photographies du soleil de l'observatoire de Meudon, on n'en trouve que très peu sans réseau photosphérique. Parmi les meilleures faites dans l'intervalle de quelques minutes on ne reconnaît plus les mêmes granules. Et même les photographies faites simultanément avec deux lunettes semblables n'ont donné aucune ressemblance dans les détails de la surface solaire.

This last fact is quite surprising, as the clear places of these photographs represent unquestionably the true granules of the photosphere; unless, indeed, they were so spoiled by the spurious *réseau*, that the places which were clear on one photograph happened to be troubled on the other.

As to the cause of these troubles, M. Hansky looks for it in the atmospheric waves between the object glass and the sun. This does not seem at all impossible, but as it is not altogether evident, there is room for some other assumption, and as the matter is worth discussing, the arguments in favor of a contrary opinion will not be out of place here. Since the phenomenon is not solar, we can assume: (1) that it is produced by waves of the air, there is no other cause to answer for it; (2) that these waves, whether inside or outside of the telescope, must be remote from the object glass and near the focal plane, if inside; or so distant, if outside, that their image may be formed near the focal plane. Now if we suppose that these areas of confused granules are images of outside waves, it seems quite evident that they will be printed on plates placed at the focus of the refractor, as well, and as often as in an enlarging camera. Indeed, every atmospheric wave at infinite distance for a refracting system equivalent to an object glass of 20 meters focal length, will certainly be so for a telescope of 7 meters. But according to our own experience,

this is not a fact. While this *réseau* is quite frequent when working with an enlarging camera, it is but slightly marked here and there on the plates placed at the focus of the refractor. Whenever the images of the sun are very fine, the granules of the photosphere are brought up on the latter plates, equally quiet and well shaped everywhere. Soon after, when working with an enlarging camera, we see the granules appear here and there quiet, here and there confused, here and there as if blown with a tremendous wind.

As this fact is general, I conclude: first, that the cause which brings up the areas of confused granules, so strongly and so generally marked on photographs obtained with an enlarging camera, is not outside, but lies somewhere inside of the telescope, and depends on some of the new conditions introduced by the camera; and secondly, that this fact entitles us to suppose that very probably the similar markings which appear on plates placed at the focus are due also to waves inside of the telescope.

Among the new conditions introduced, the most striking is certainly the addition of a new refracting system very near to the focus of the first object glass. It cannot fail to be intensely heated and consequently the air brought in contact with it must be set in motion. This lens, at least when it consists of a large concave lens placed inside of the focus of the telescope, is not contributing with every part of its surface to the formation of the image of every point of the sun. The rays of light, converging to form the image of a point, pass through only a portion of it. Small waves on its surface therefore may disturb several parts only of the image, and produce the so-called photospheric *réseau*. In case of a convex magnifying glass, the disturbances in the focal plane of the telescope would be photographed together with the image of the sun. As no other condition introduced by the enlarging camera seems so adequate to the production of this phenomenon, we may rationally suppose that it is due to this cause.

Guided by these considerations, I tried some experiments to see how far facts would support my view. I used an enlarging camera, first shutting out the rays of the sun some distance ahead of the magnifying lens and admitting them just at the time of releasing the shutter. I then allowed the rays to reach the lens for some time before releasing. If the *réseau* is produced by the lens the photographs

would be different in the two methods. Otherwise they would not. I found that there was always much to be gained by the first mode of operating, and the longer the exposure to the sun, even within five minutes, the worse were the photographs.

The magnifying system employed in these experiments is formed with two lenses. The first, which is carried inside of the focus of the telescope, is a convexo-concave lens of 30 mm aperture; the second, at an invariable distance from the first, is a biconvex lens of still less diameter and focal length. Besides photographing only a small portion at a time, the system is probably otherwise ill adapted for photography of the sun. The air inclosed in the brass tube between the two lenses must be intensely heated and set in motion. I hope soon to be able try another system and complete these experiments.

As to the traces of this *réseau* found on plates placed as the focus of the telescope, though I could not for the present assert anything, I incline to think that they are due also to air waves inside the telescope. We can well fancy such a combination of short atmospheric waves that would produce this effect. But whether this conception is consistent with the state of our atmosphere is not so evident. Although I do not intend to discuss all the conditions requisite for good photographs of the photosphere, I think advisable to discuss here two opinions which are generally held by astronomers.

The first is relative to the dimensions of the images necessary to bring up the details of the photosphere. M. Janssen in his note on the photospheric *réseau* (*Annuaire du bureau des longitudes*, 1878) wrote: "Les images dont le diamètre ne passe pas 10 à 12 cm ne peuvent montrer les détails de la structure photosphérique." This assertion, based on the experiments of the author, must be accepted as undoubtedly true under the conditions in which he was working; viz., with an object glass of a rather short focal length and a magnifying system. But it cannot be extended to the case of an object glass of a rather large aperture with a proper focal length. In fact, we get at Zô-sè the details of the photosphere on images of scarcely more than half the size specified, viz., 63 to 65 mm. This may be the smallest possible size, as most of the granules are not more than 0.03 mm in diameter on such photographs. But this shows that a simple object glass of long focal distance with a convenient aperture

is far better than any other system of refractors. The second question is relative to the time of exposure necessary to bring up the details of the photosphere. Mr. Maunder, at a meeting of the Royal Astronomical Society in speaking of the photography of the sun at Greenwich, said:

> The great difficulty in solar photography is getting the exposure sufficiently short, and in summer time the normal exposure given is equivalent to $\frac{1}{3000}$ part of a second. This in order to bring up spot detail. To bring up granulation detail, as in M. Janssen's photographs an exposure shorter still must be given.[1]

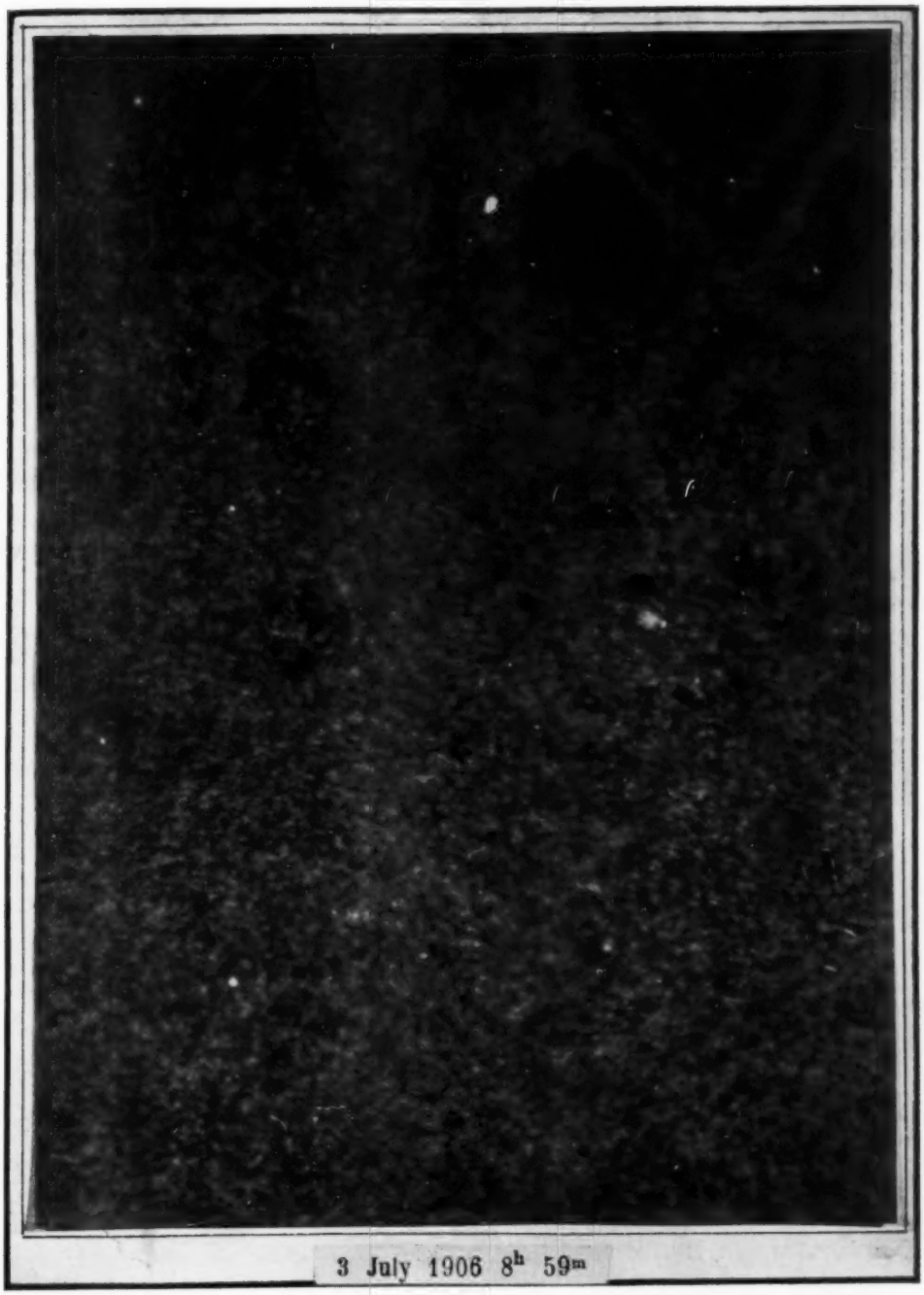
There are two points in the statement of Mr. Maunder which do not agree at all with our experience at Zô-sè: first, that to bring up photospheric detail it is necessary to give a shorter exposure than to bring up spot detail; second, that so short an exposure as $0^s.0003$ is necessary to bring up spot detail. If by spot detail he intended to include only the larger features of a sun-spot, as umbra, penumbra, and bright "bridges" over the umbra, we should agree with him that they are more easily brought up than the photospheric details. But if, as we think, the thin filaments of the penumbra, or faint details of the umbra were meant, then our experience is certainly to the contrary; it is much easier for us, with the same exposure, to bring up the photospheric details. With our object glass diaphragmed to 30 cm the exposure for a plate at the focus of the telescope is $0^s.001$, but is equivalent to $\frac{1}{3000}$[2] part of a second as at Greenwich. When working with a camera magnifying the image to eleven diameters we make the exposure equivalent to $0^s.001$. In case of fine and quiet images, a rare occurrence indeed, we do not find these exposures to be too long either for photospheric detail or for spot detail. In other cases, the shorter the exposure the less the photograph is troubled by the motion of the air in every kind of detail.

It would be interesting to know whence come these differences; but I can only surmise that the kind of plates used and the method of development adopted have much to do with them. We have tried plates of several makes and found that, for clearness of the image and plenty of minute details, there are enormous differences between

[1] *The Observatory*, **30**, 76, 1907.

[2] The slit of our shutter is 1 mm broad, its speed is nearly 1 mm in $0^s.0003$; on account of its distance from the plate, the strip of plate exposed at one time is 3 mm broad.

PLATE II



SOLAR PHOTOSPHERE

plates even when nearly of the same sensitiveness. All the chloride or so-called lantern plates have been found by far inferior, for this work, to the slow bromide plates, such as the Lumière Red Label plates.

I come now to the results of our research on the granules of the photosphere. I will say a few words on their dimensions and forms, their duration, and their movements on the surface of the sun. As all these results depend on our photographs, I must first present to the reader the plates selected to illustrate this paper.

The first is an enlargement to eleven diameters of a photograph obtained on July 3, 1906, at $8^h\ 59^m$. It is specially intended to exhibit on a convenient scale a portion of the photosphere, large enough to show its general appearance. It is not the best specimen we could produce, but it has been purposely selected for the traces of photospheric *réseau* it bears. There are certainly disturbed places, but details are not all confused beyond recognition. The two following plates are intended, on the contrary, to make clear the minute details of the granules of the photosphere. The enlargement of the original plates has been carried to 33 diameters so that one millimeter on these photographs represents only $0''.9$ on the disk of the sun. Each plate contains a set of two photographs taken within one minute of each other; and the portion of the disk found on the two photographs is exactly the same. The differences observed in the granules of the two images therefore must, if we were not mistaken, be accepted as representing changes which really took place on the surface of the sun. Defects of the film of the original plates have been purposely left uncorrected, but they are apparent, and with some caution the reader will distinguish them from the true features of the photosphere. When one takes several photographs of the sun within a short space of time, many differences are often noted mostly coming from difference in clearness in the photographs. But I think that in the present case the reader will distinguish what is due to a defect of the film or to differences in clearness from what is caused by real changes in the photosphere.

Form and dimension of the granules.—The diameter of the granules as measured on the present photographs varies nearly from $1''$ to $3''$. It would be quite useless to measure a great number of

them in order to get a mean diameter, inasmuch as their edges are by no means sharp and definite. We must rather inquire whether 1″ is really the lowest limit of the granules. In fact, on the original plates, 1″ represents 0.03 millimeter, which is very nearly the smallest detail obtainable by photography, especially with such a difficult object as the sun. On pictures of sun-spots taken with the help of an enlarging camera, the lowest limit is certainly below 1″. For instance, on the photograph of a sun-spot reproduced in the *Astrophysical Journal*, May 1907, many granules were found, particularly near the spot, the diameter of which does not exceed 0″.3; and in many places it looks as if the larger granules were formed by the union of smaller ones. I found indication of the same formation on several other photographs taken with the same instrument. And of course it is very probably so. There is, however, no substantial difference between the photosphere and its granules as they appear on these photographs, and those we now present, obtained by enlargement of plates taken at the focus of the telescope. Everyone can see for himself that the granules are of a more or less circular form, or rather, are ellipses of small eccentricity. This common shape is often altered; but very generally it looks as if it was so by outward circumstances, as pressure from other granules, union with some other one, etc.

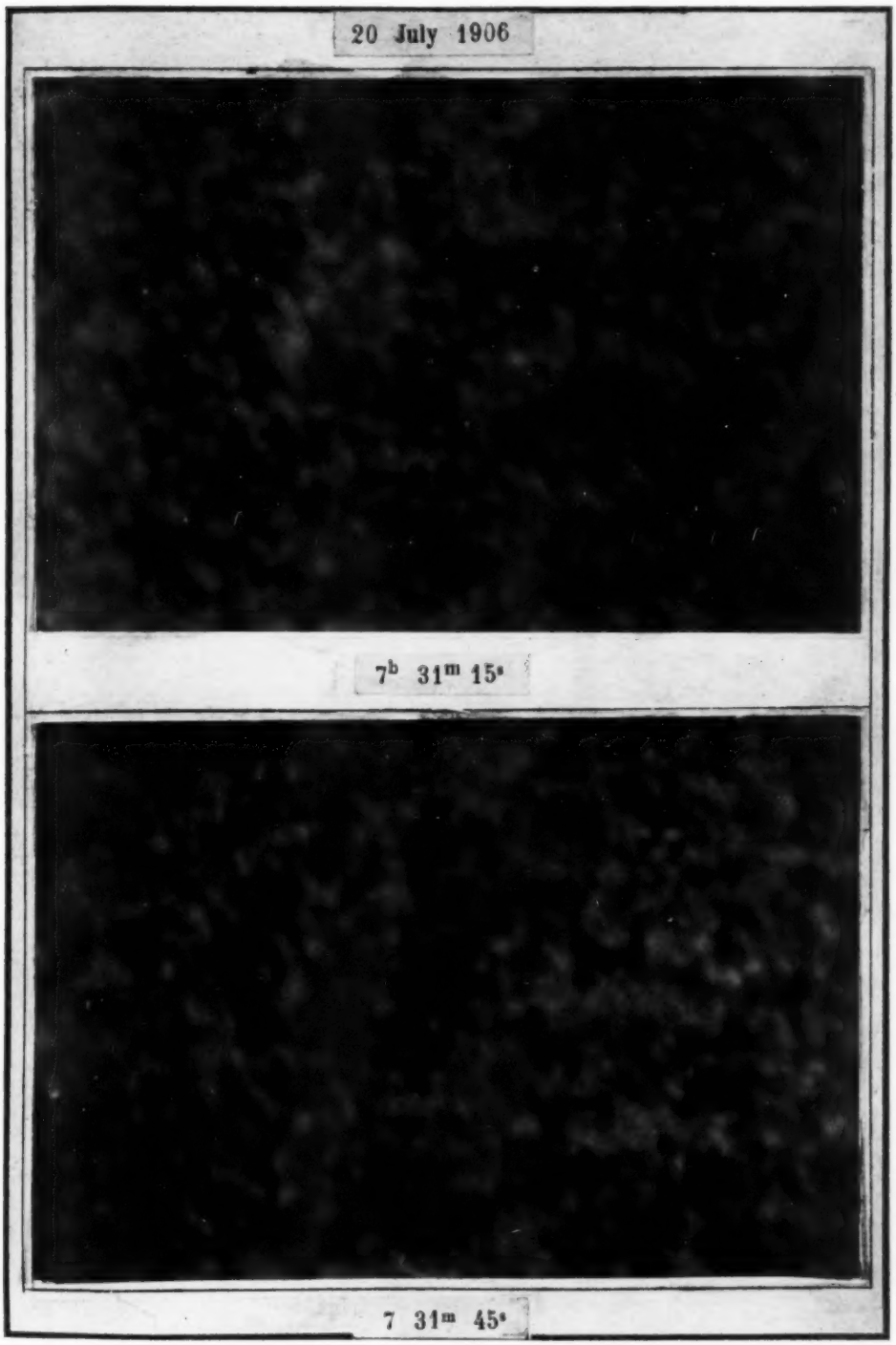
It would be a mistake to look at those granules as at individual clouds without any connection. It is easy to see that there are four, five, six, or more of them grouped together to form what might be called primary groups, which combine together to make larger figures. The quite irregular shape of these figures is marked by broad dark lines meandering through the groups of brilliant granules. They form a compact net of a true photospheric nature. Plate I shows a great number of these lines.

Are these broad or narrow dark lines identical in substance with that of the brilliant granules they are meandering through; or are they a part of the gaseous atmosphere in which the granules, or photospheric clouds, are floating? Young[1] writes: "They (the granules) are luminous clouds floating on a less luminous atmosphere." Secchi[2] says: "Les grains paraissent comme suspendus

[1] *Textbook of General Astronomy* (revised edition, p. 196).

[2] *Le soleil* (2e édition, 1re partie, p. 52).

PLATE III



DETAILS OF PHOTOSPHERIC STRUCTURE

dans un réseau noir et entremêlés de nœuds plus ou moins sombres, plus ou moins larges." That the granules are clouds of condensed particles, either liquid or solid, seems unquestionable, but that the darker lines consist of a gaseous atmosphere in which the clouds are floating is not so evident. They may be as well formed of the same particles, less luminous only because, being at a lower level, they are covered with a thicker stratum of chromosphere and reversing layer. With all respect to the high authority of Young and Secchi, I think the latter view is more consistent with the aspect of the photosphere on photographs, as well as with spectroscopic observations. On the photographs the photosphere looks like an extended and unbroken layer. It must be formed of condensed particles of many of the substances composing the gaseous mass of the sun. The external surface exposed to our sight, far from being plane and uniform, presents an aspect much like the fleecy form of our alto-cumulus clouds.

Here arises a question the solution of which would be of great interest, viz., are the granules always of the same form; or are there various forms of photospheric clouds, just as there are widely different forms of atmospheric clouds? Secchi[1] gives three drawings of the photosphere, Figs. 21, 22, and 23 of his work, and says:

> La comparaison des différents dessins que nous reproduisons peut faire apprécier les différences d'aspect que présente la photosphère, suivant les époques où on l'observe, et peut-être suivant les observateurs et les moyens qu'ils emploient.

In this last sentence, Secchi took a very wise stand. In fact, if the differences of the drawings represented true changes in the photosphere it would be evident that there are photospheric clouds as widely different from each other as our various kinds of clouds. But very probably, and, I dare say almost certainly, they are merely differences of clearness of the images at the focus of the refractor. I could easily produce photographs showing as much difference in the photosphere, but never with the same clearness of the images. Whenever the plate does not show the granules distinctly there is on the plate a lack of clearness, which becomes evident when examined with a powerful lens, or when enlarged to 20 or 30 diameters. In such cases, on account of a disturbed atmosphere, merely the primary

[1] *Loc. cit.*

groups of granules, or even the larger groups alone, are brought up on the photographs. Whenever the photograph is very clear it exhibits a photosphere very nearly the same in its general aspect as the photosphere of any other day, and the differences are not easy to grasp and describe clearly. It is supposed that the granules are now more circular, now more elliptical, sometimes larger, sometimes smaller. I also surmise some systematic differences in the grouping of the granules as well as in the form of the meandering dark lines of the photosphere. But I have not come to any definite conclusion. This field of investigation is new and difficult. We hope to be able to give it more attention.

Duration of the granules.—The time that elapses between the formation of a granule and its disappearance is very short. After only ten minutes or so nothing remains that can be recognized on the surface of the sun except spots and faculae. I have compared photographs taken at intervals of seven minutes, and not a single granule of the first could be found on the second. But there were still several features of the broader dark lines, several of the larger groups of granules which, though much altered, could still be recognized, as remains of the photospheric clouds brought out on the first photograph. On comparing other plates taken at an interval of two minutes and a few seconds, I found that although many groups of granules were changed in form, most of their features were still easily recognizable and the individual granules had not yet all disappeared.

The two photographs of July 24, on Plate IV, were made at an interval of 50 seconds. Quite a number of individual granules are found on both, with hardly any change. Some are altered in their shapes, some are more conspicuous on the first plate and have grown fainter or smaller on the second; some, on the contrary, have gained in size. On account of the differences in the plates themselves, the recognition of the real changes in the granules requires much attention. As to their explanation, my impression is that some granules look brighter or larger simply because they have risen to a higher level, while others have sunk down, and consequently have become less brilliant. We cannot say how far this rapidity of formation and change is constant. Is there any connection between the periodical activity of the sun and this rapidity of change in the photosphere?

PLATE IV

DETAILS OF PHOTOSPHERIC STRUCTURE

This is an unexplored field of research which promises results of real interest.

Horizontal movements of the granules.—In the paper already referred to, M. Hansky paid a great deal of attention to this subject, and excited the widest interest in declaring that the granules of the photosphere were moving on the surface of the sun with enormous velocities reaching to 40 km a second. I was the more interested, as I was at the time engaged in a study of the photosphere. I easily realized how necessary it was to take up the important research so admirably initiated by M. Hansky, and included in my studies the measure of the movements of the granules. I give my measures with all reserve, as it is very difficult to reach any accuracy in measuring the displacement of a granule. Indeed the displacement to be measured is small relatively to the diameter of the granules, which are, moreover, inconstant in shape, while their edges, and consequently their centers, are far from being well defined, with the result that there is a complete want of a fixed point. On the other hand, in computing the velocity of the granules, the error of measurement is divided by 30 or 50, the number of seconds elapsed between the two photographs—a circumstance which makes it possible to obtain a better determination. I think it best, therefore, to explain how I endeavored to get as fair measures as possible, and how the values obtained were tabulated. A few conclusions will then be given.

For each pair of photographs I first made two positive plates, and looked for all the granules which were perfectly definite on both. On each plate I marked with a red dot the center of each granule. Having so marked many granules, I superposed the plates, trying to obtain as fair an agreement of the granules, throughout the two plates, as I could. Taking every care to avoid parallax, I marked on the upper plate the red dot of the lower one, wherever it did not prove coincident with the upper one. I then took away the upper plate on which the horizontal movements of the granules were shown by the distances between the red dots. The plates were examined again to see whether some slight error had been made in pointing the centers, and the distances of the red dots could be attributed to such errors. In several instances where the displacement was very

small, it might easily have been so; as also, where the centers had been considered as coinciding, a very small displacement was not altogether impossible. But I was satisfied that the distances I had obtained were, on the whole, as close an approximation to the truth as could be hoped for. Micrometric measures would have been easy but to no purpose. The distances were consequently measured to one or two tenths of a millimeter with a millimetric rule and the help of a magnifying glass.

To transform the resulting distances into kilometers, I made the half-diameter of the sun equal to 697,130 km and 15′ 46.″7 at the end of July. In consequence, one millimeter in the center of the disk will be equivalent to 670 km. As the part reproduced here is sufficiently near the center, we may use this value throughout the three pairs of photographs. Besides these three pairs of photographs, another one obtained on October 13, 1906, was also measured after the same method. This was chosen rather distant from the others, to see whether any considerable difference could be found. For this last plate the value of a millimeter has been made equal to 656 km.

The following table gives the results and contains, with the dates and the time elapsed between the two photographs, the number[1] of granules measured, the number of granules found to have no movement, the maximum displacement measured and corresponding velocity per second, with the number of granules having reached this velocity. I have added in the last two columes the mean of the displacements measured, and the mean resulting velocity. The mean of so widely different members is in a way meaningless; but it is intended to give, with the number of motionless granules and the maximum displacement of a single granule, some idea of the average

Dates	Time Elapsed	Granules Measured	Motionless Granules	Maximum		Granules	Mean	
				Displacement	Velocity		Displacement	Velocity
				mm km	km		mm km	km
July 20, 1906	30^{s}	46	9	1.1 = 836	33	1	0.34 = 228	9
July 21, 1906	29	38	12	1.1 = 836	28	1	0.41 = 273	8
July 24, 1906	50	54	12	1.5 = 1005	20	1	0.67 = 449	9
Oct. 13, 1906	30	54	25	1.2 = 787	26	1	0.36 = 236	8

[1] The plates measured are much larger than the present photographs.

of the displacement measured, without printing a full table of the measures which do not seem to be of any importance.

The maximum velocity reached by a few individual granules agrees fairly well with those measured by M. Hansky. But the mean velocity is so much lower, and there are so many granules which do not move at all, that the tremendous velocity obtained for several granules seems to be suspicious. The quantities to be measured cannot be, indeed, defined more accurately than to 0.1^{mm} or 0.2^{mm}, which represent 2 and 4 kilometers. But these are low figures compared to those of the maximum velocities, which consequently cannot be due to errors of measurement.

But whatever the inevitable inaccuracy of the above figures, it does not affect the conclusions which, I think, can be expressed as follows:

1. If any portion of the photosphere be compared on plates taken at a minute or a half-minute interval, most of the granules will be found substantially the same and perfectly recognizable.

2. These granules have generally, however, experienced many obvious changes as to their shape and brilliancy.

3. On looking more attentively it is found also that many of them have changed their relative positions.

4. The displacements of the various granules differ widely, ranging from zero to thirty or more kilometers a second.

5. These displacements are as widely different in direction as they are in velocity, each granule going its way without relation to the movements of others in its neighborhood.

6. The displacements observed in several granules reach sometimes to enormous figures when expressed in kilometers, but they are small if compared with the diameter of the moving granule. In fact no granule, I think, during the course of its existence moves so much as the length of its diameter.

The question now arises whether we are contemplating true movements along the surface of the sun, or mere changes of shape and form in the granules, by vertical motion of the condensed particles. If it be supposed that the granules are luminous clouds floating in a less luminous atmosphere, as clouds in our atmosphere, and it is found that they are moving through this atmosphere, or with it, at

the tremendous velocities of 20, 30, 40 kilometers a second, we are certainly in the presence of a most important phenomenon. But this supposition does not seem consistent with the above conclusions. Such enormous horizontal velocities of some granules, in the neighborhood of which there are other similar granules which do not move at all, or move in different directions, and at different rates, seem to be almost beyond comprehension.

Let us admit, on the contrary, that the granules are the summits of a fleecy stratum of condensed particles, with or without any horizontal movement; and that the stratum is subject to undulatory movements; the summits of the waves will then present the same succession of changes; their relative position varying in every direction and with any velocity. The short, quickly changing waves of a choppy sea may possibly give us a faint imitation of what is realized on a gigantic scale and in a very different element in the solar photosphere.

Zô-sé Observatory
Près Zi-ka-wei, China
Oct ber 1907

ON TWOFOLD LINE-SPECTRA OF CHEMICAL ELEMENTS[1]

By E. GOLDSTEIN

In recent years I have been led to investigate the emission spectra of a number of elements, particularly the alkali metals and the halogens, more thoroughly in some directions than has hitherto been done.

In the course of these researches I have found that caesium, rubidium, and potassium each possess two line-spectra which do not have a single line in common. Differentiation of the two spectra is not effected simply by inference, but is accomplished experimentally. Under certain definite experimental conditions one may obtain solely the lines of the one spectrum or solely those of the other; the one coincides with the arc-spectrum of the metal in question, but may also be produced by weak electric discharges; the other is evoked distinctly by heavy discharges from a condenser.

A number of the lines of the new spectra had already attracted attention: several of the new potassium lines were observed by Lecoq de Boisbaudran,[2] but were assigned by Kayser and Runge[3] to suspected impurities. Similarly a number of these lines occurred among those observed by Eder and Valenta;[4] and for rubidium and caesium in those of Exner and Haschek[5] from the ultra-violet to the blue (about λ 460). But in these investigations also the new lines appear on the use of discharges from jars only in addition to the long-known lines of the elements, so that from them the only conclusion which could be drawn was that the arc-spectra of the alkalies mentioned were enriched by a number of lines on employing the spark from condensers; while the arc-spectra persist.

[1] A preliminary communication to the Deutsche physikalische Gesellschaft, dated August 14, 1907. Translated from *Verhandlungen*, 9, Nos. 15, 16.

[2] *Spectres lumineux*, Paris, 1881.

[3] *Abhandlungen der Berliner Akademie*, 1890.

[4] *Sitzungsberichte der Wiener Akademie*, June 1894.

[5] *Wellenlängentabellen*, Leipzig und Wien, 1902.

The methods I have employed, to be described in a more extensive communication, in effect consist in raising the density of the discharge, referred to the mass unit of the metallic vapor, decidedly beyond the previous limits. With an adequate increase in this respect it is observed that the long-known lines of the three metals entirely disappear, while new lines appear in great brightness which coincide with no arc lines. Inasmuch as the arc lines of the alkali metals are all series lines, while the new lines fit into no series, we may therefore make for these three metals the statement: *Powerful discharges extinguish all the series lines and replace them by non-series lines.*

The color of the discharge changes very strikingly in the transition from one to the other spectrum: for instance, for rubidium it changes from a rose red (series spectrum) into a brilliant sky blue; in the case of caesium, from a bluish red into a greenish gray-white.

The strengths of the discharges necessary to cause the lines of the new spectra to appear increase in succession from caesium through rubidium to potassium. They are therefore greater as the atomic weight is smaller (*Cs*, 133; *Rb*, 85; *K*, 39). In the case of sodium (atomic weight 23) I have hitherto succeeded only in producing a very decided weakening of the series lines, but not in extinguishing all the series lines and replacing them by a new spectrum; for lithium (atomic weight 2) the effect is the least. In respect to the effect of the atomic weight mentioned, the suspicion seems to me permissible, however, that with experimental conditions permitting a further increase in the density of the discharge, the long-known sodium spectrum would also disappear in all its series and be replaced by a new one. The same thing may be suspected for lithium.

If two wholly different line-spectra are to be ascribed to the alkali metals (thus far to *Cs*, *Rb*, and *K*), this result departs pretty widely from the original assumptions in spectroscopy, and the question suggests itself whether a support for this is found in our experience in other directions. We may point in this respect to some of the new monatomic gases, in which similarly twofold line-spectra are observed, namely, in argon, krypton, and xenon. We further recall the beautiful research in which Lenard[1] showed for the alkali metals that different

[1] *Annalen der Physik*, 11, 636, 1903; 17, 197, 1905.

particles may radiate differently in the electric arc, emitting either the principal series only or one of the subordinate series, according to their temperature.

The most obvious assumption in view of such behavior appears to me to be that the metallic vapor in the arc forms different isomeric (or polymeric) aggregations according to temperature, and that to every aggregation a particular series of vibrations corresponds, the type of which remains the same, however, for the different aggregations of the same element. In support of such an assumption, perhaps the observations[1] may serve which have been made on the discontinuous emission spectra of solid organic bodies in which isomeric substances (for instance, the three xylols) exhibit an identical spectral type (form of grouping of the maxima), but have different wave-lengths of the comparable maxima. In these bodies only a single type of structure, the ring of six members of the aromatic group, is capable of furnishing such regular phosphorescence spectra consisting of narrower or broader bands. If the ring is broken on forming other configurations, the regular spectra cease and a continuous emission only remains.

It may be that the association of the particles in different and regular groupings is a prerequisite[2] also for the regular gaseous spectra (band-spectra and series spectra). If these regular structures are destroyed by excessively powerful forces (condenser discharges) and separated into single particles, the regularly constructed spectra also disappear and only the non-series lines occur, which therefore would properly be the ones corresponding to free or isolated gas particles.

It may be permissible to distinguish these spectra belonging to most elementary conditions by a name, and designate them as the "fundamental spectra" ("Grundspectra") of the substances in question.

For slight intensities or densities of the discharge, therefore, only groups of gas particles would be luminous; for moderate intensities

[1] E. Goldstein, *Verhandlungen der phys. Gesell.*, **6**, 156, 185, 1904.

[2] Such groupings may be caused in various ways, as for instance by ionization. The view that a material disintegration is connected with the ionization of gas particles is apparently giving way more and more to the view that associations occur with ionization. The last investigations by J. J. Thomson yield a threefold mass of hydrogen atoms for ionized hydrogen particles.

of the discharge a portion of the combination would be split up and the two spectral types would appear superposed, corresponding to the mixture; with the most powerful discharges only isolated particles would exist with the fundamental spectrum. The previous investigations of the alkali metals by Lecoq, Eder and Valenta, Exner and Haschek, and others, were made at moderate intensities, which were strong enough to split up a portion of the combination and thus permit the appearance of the lines of the fundamental spectrum in addition to the series lines of the remaining portion of the combination; while they were not strong enough to break up all of the groups and thus to extinguish the series lines. Tables and drawings of the fundamental spectra of caesium, rubidium, and potassium are to be published later, based upon the photographic plates. In this communication only the positions of the brightest maxima will be given. The brightest lines of the fundamental spectrum of caesium have the following wave-lengths:

λ 592.8	525	487
583	523	483
556	505	466
537	497	460.3
535	495.5	

The bright caesium lines at λ 459 and λ 455, which are so characteristic of the arc and flame spectrum, are invisible, as are all the remaining lines of the series spectrum. The number of the fainter lines is considerably larger. The caesium spectrum extends beyond *Hα*, forming in the red from about λ 600 to λ 645 a series of numerous and closely packed although not specially bright lines.

This renders more striking the scarcity of lines in the red portion of the fundamental spectrum of rubidium, the series spectrum of which is characterized by several very bright lines just in this region. The bright lines of this fundamental spectrum do not begin until the green is reached, and its brightest lines are:

λ 552.6	453
515.2	429.5
477.7	427.3
457.6	424.8

Potassium has in the red portion two bright lines at λ 624.5 and 630 in addition to the line at λ 611 previously noted by Lecoq. The less bright lines will be communicated later. Lecoq also observed several lines of the fundamental spectrum in the green and blue mixed in with series lines. The brightest lines of this potassium spectrum are at wave-lengths:

λ 630	483	439	418
624.5	461	431	415
611	451	426	413
501	447	422	411

For comparison I add the principal lines of the series spectrum of potassium:

λ 770	581	532
767	580	404.7
694	578	404.4
691	536	
583	534	

The suspicion naturally arises that the occurrence of different line-spectra for one and the same element may not be limited to the alkali metals (and several monatomic gases). There are in fact several indications that we are here concerned with a more generally extended property, although nothing definitive can be stated at present. For a long time strong differences have been known to exist between the arc-spectra and spark-spectra of different metals. If, for instance, we compare tables or photographs (such as Hagenbach & Konen's *Atlas der Emissionsspektren*) of arc and spark spectra of silver, zinc, cadmium, copper, and mercury, we find a number of lines which are more or less weakened or extinguished, in the transition from the arc, as has already been pointed out by numerous writers. But in this transition by far the greater portion of the lines appearing in the arc always remain and *increase* in brightness.

If therefore the two line-spectra should be assigned to these metals (other metals exhibit similar properties), then both spectra would appear mixed in together at the slightest density of discharge hitherto applied, or at the lowest temperature. They cannot be experimentally separated until the spectrum can be reduced to a number of lines at a relatively low temperature, which are all suppressed at a

high temperature (heavy discharge) and are replaced by lines in other positions. Until then the two spectra from these metals could be separated only as a matter of theory. In this manner J. Stark[1] has actually assumed that two line-spectra exist for mercury. For the view that the twofold line-spectra represent a widely diffused property, it seems to me confirmatory that it occurs in the case of elements which stand as far away from those hitherto treated, as is the case for the halogens, although not in so pronounced a manner as for the alkalies, but more obviously than for the other metals just mentioned.

A closer study of the halogens according to the process which I sketched long ago[2] leads to this view. This process, as was then explained, enables us to produce the band-spectra of bromine and chlorine. The more thorough investigation which I have just completed now yields the result that a series of lines are superposed over these band-spectra somewhat as the four-line spectrum of hydrogen overlies its band-spectrum. If powerful discharges are now passed through tubes of bromine and chlorine the greater portion of those lines become invisible,[3] while another portion of the lines becomes bright, and furthermore, new lines become brightly luminous. Overlying the band-spectrum of diluted bromine appeared the following lines:

TABLE I

λ	Int.	λ	Int.	λ	Int.	λ	Int.
782	1	640	2	539.5	2	475.6	2
753	3	635	6	534.7	2	472	1
735	3	629	1	530.8	2	470.7	4
727	1	628	1	524.2	5	468	2
716	2	620	2	518.2	5	461.5	2
711	2	617.5	2	517	2	457.6	4
700	4	615.3	1	505.5	1	451.5	3
678	4	615	6	498.3	5	452.6	3
673	2	613	2	493	2	448	4
668.5	2	610	1	492.5	2	447.5	4
667	2	585	2	482	4	444.2	3
663	5	577.8	2	478.5	5	436.3	2
655	1	559	2	478	5	422	2
654	5	547	2	477.2	1		
648	1						

[1] *Annalen der Physik*, 4, 16, 490, 1905.

[2] *Verhandlungen Berliner Phys. Gesell.*, 1886, p. 38.

[3] Hazy traces appear on long exposures in case of the strongest of the lines which are extinguished to the eye. A further increase in the intensity of the discharge would presumably also extinguish these traces.

The intensities are estimated on a scale of 6 steps, where 6 represents the greatest brightness. Of these lines, the following disappear on connecting in the Leyden jar:

782	668.5	585	457.6
753	667	577.8	452.6
735	663	547	451.5
727	655	539.5	448
716	654	534.7	447.5
711	620	498.3	444.2
700	617.5	478	
678	615.3	475.6	
673	615	461.5	

There were not included in the above tables several lines for which it remained uncertain whether they persist or whether they are extinguished and replaced by new lines very close to their positions.

Thus at least 33 of the 56 lines are extinguished by the jar.

What we have hitherto regarded as the spectrum of bromine is a mixture of lines which may be extinguished and of the lines of the fundamental spectrum. The occurrence of the mixture depends, as in the case of the alkali metals, upon the fact that in the previous investigations the density of the discharge (referred to the unit of mass of the gas) could not be sufficiently great, for reasons to be presently mentioned. The discharge tubes used had electrodes which gradually absorbed the gas, forming bromides or chlorides, even for slight intensities of the discharge. Therefore the tubes could not be filled at a low density. But intense discharges (of the Leyden jar) were wholly excluded, because then the absorption by the electrodes would take place in a fraction of a minute. Hence it resulted, under the conditions of the experiment which practically had to be employed, that the densities of discharge were such that a number of the lines given in Table I were extinguished and therefore necessarily remained unknown; while these intensities of discharge were able to weaken a series of other particularly bright lines only to such an extent that they could be cited in the previous lists of lines of bromine as the principal characteristic lines. For instance, among these belong the following bright lines which have hitherto been regarded as characteristic for bromine:

λ 699, 615, 452.6, 448, 447.5, 444.2.

A sufficient increase of the intensity of the discharge makes them all invisible.

In the case of chlorine 24 lines were extinguished in this manner, which appear when the capacity is not used. The brightest of these chlorine lines which are suppressed at even moderate intensities of the discharge are:

$$\lambda\, 753,\ 741,\ 725,\ 614,\ 466,\ 461,\ 453,\ 439.$$

It has not been possible hitherto to establish a perfect agreement with the behavior of the alkali group, as pointed out above; since in case of the alkali metals, *all* of the lines which appear together under certain conditions may be extinguished, but in case of chlorine and bromine only a considerable number of them. In case two wholly different line-spectra exist for chlorine and bromine, their complete separation has therefore not yet been experimentally accomplished. Groups which can be extinguished, however, appear to be purer as the width of the tube is increased, or therefore, other things being equal, as the density of the discharge is less (which is also true of the luminous intensity). The investigation will be continued in this direction.

The investigation of iodine for the presence of two line-spectra is rendered difficult by the fact that the brightness of the background changes very greatly on throwing in the jar, so that judgment as to the change of brightness of many of the lines is rendered uncertain. It could be recognized, however, that a number of lines which are suppressed in the band-spectrum of iodine, e. g., λ 524, 520, 512, 491, differ decidedly in their behavior from many other lines.

These investigations establish for the first time the forms assumed by the spectra of chlorine and bromine when these gases in an attenuated condition are traversed by powerful jar discharges. Earlier investigations were frustrated by the above-mentioned action of the gases on the material of the electrodes. The tubes which I employed were coated with tinfoil on their external surface only. There seems to be a widespread belief that powerful condenser discharges cannot be passed through such tubes with external coating, but this supposition is incorrect. Such a tube can be connected in parallel with a jar just as an electrode tube. If an air-gap is then inserted in

the circuit leading to the internal coating of the jars, powerful condensed discharges of great brightness will pass through the tube, which also differ in the altered color of the discharge from those which pass through the tube when a jar is not used. The color of the discharge thus changes for bromine from peachblow into greenish blue, for chlorine from white to green, for iodine from chamois yellow to green.

Such condenser discharges in passing through the halogens give spectra exceedingly rich in lines which may be observed with very slight density of the gas as long as may be desired without any development of combinations by the gas or alterations of its density. The spectra thus far exceed in the number of lines those hitherto photographed for chlorine and bromine. The most complete representation of the chlorine spectrum hitherto produced is due to Eder and Valenta.[1] They cite in all 110 lines between λ 546 and λ 400. On plates of the same region I obtained twice as many lines, even with the relatively slight dispersion of a single Rutherford prism, which permitted many doubles and close groups to appear as single lines. The increase in number of lines is similar in the case of bromine.

The process I have used gives especially striking results in the least refrangible portion of the spectrum. Plücker and Hittorf[2] record 5 lines for chlorine from the extreme red to λ 600, or 16 lines in all to λ 546. (The observations of Eder and Valenta begin in the yellow.) My plates give 34 lines in all to λ 600, and more than 80 to λ 546.

For bromine the farthest line to the red hitherto was the line observed by Salet at λ 699; five other lines were observed by Salet in passing to the yellow. Eder and Valenta give λ 668 as the farthest line and 15 others to λ 600; my observations show that the condenser spectrum of bromine extends beyond λ 700, and that from its extreme limit to λ 600 it consists of a closely packed series of several dozen lines, of which a portion become somewhat diffuse with intense discharges. Visual observations show still more lines than the photographic plate in this closely packed series, because with the relatively small dispersion on the plate the neighboring lines often coalesce.

A description of the most suitable dimensions of the tube and

[1] *Sitzungsberichte der Wiener Akademie*, April 1899.

[2] *Phil. Trans.*, **155**, 1, 1865.

technical particulars as to the mode of filling them will be given in a more extended paper, in which I shall also give another description of the spectra of the halogens. These discoveries as to double spectra and the assumptions indicated above as to the origin of the series-spectrum, suggest a number of conclusions, as well as new investigations.

If the series spectra in fact depend upon association of gas particles into complex groups, then it would seem to be theoretically possible that all such groups could be experimentally broken up and thereby the fundamental spectra of the isolated particles could be obtained. On this basis entirely new spectra could be expected, for instance in the cases of hydrogen and helium. We cannot regard such suspicions to be contradicted by the fact that these two gases have already been often investigated with discharges of great density. The atomic weight might here also be influential, and if the appliances which are effective for large atomic weights already fail at an atomic weight of 23, then elements with atomic weights of 4 and 1 might oppose a very much greater resistance to the breaking-up of the complex groups. There is possibly also a connection with the fact that xenon, krypton, and argon, with atomic weights of 128, 82, and 40, respectively, exhibit twofold line-spectra, while for neon (atomic weight 20) only one spectrum has thus far been observed.

Another investigation suggested would be to see whether the apparent absence of potassium, rubidium, and caesium from the sun might be due to the appearance of their fundamental spectra among the Fraunhofer lines in place of the series-lines which have hitherto alone been looked for. I hope to be able to test this soon in a more suitable place than in my almost sunless laboratory.

Other questions which are raised by the twofold line-spectra refer to their behavior in respect to the Zeeman effect, to the possible charge of the carriers of the line, to the behavior of the lines in regard to Doppler's principle, etc. These questions are so obvious as to make further discussion of them superfluous for the present.

BERLIN

OBSERVATIONS OF *SATURN'S* RINGS AT THEIR DISAPPEARANCES IN 1907 WITH A SUGGESTED EXPLANATION OF THE PHENOMENA PRESENTED

By E. E. BARNARD

The interest in the beautiful ring system of the planet *Saturn* has never been greater than in the present year, when, according to calculation, the ring has been invisible. It is well known that at intervals of fifteen years the edge of the ring is presented to us and it is then supposed to disappear because of its extreme thinness. Two causes operate to produce these disappearances: first, when the plane of the ring passes through the earth; and, second, when it passes through the sun. It is possible for the ring to make two disappearances and two reappearances during this critical period. Thus in the years 1861–62 the ring twice disappeared and reappeared. Previous to this the sun and the earth had been on the south side of the ring for fifteen years. On November 22, 1861, the earth passed through the plane of the ring going north and until January 31, 1862, the earth and the sun were on opposite sides of the ring, and it was supposed to be invisible in the interval. On January 31 the earth again passed to the south side of the ring and it once more became visible, for the sunlit surface was then turned to the earth. On May 17 the sun passed through the plane of the ring, going north, thus leaving the earth once more on the dark side of the ring, which was invisible until August 12, at which time the earth passed to the north and was again on the sunlit side, where both the sun and the earth remained until 1878.

A valuable series of observations of *Saturn* was made with the 15-inch refractor of Harvard College Observatory by G. P. and W. C. Bond at the disappearance of the ring in 1848. These make part of Vol. I of the Harvard College Observatory *Annals.*

A number of the many drawings of *Saturn* given in that volume show the ring and condensations essentially as they have appeared during the past few months.

The conditions for the disappearances and reappearances of the ring in 1848 were almost identical with those in the present year. The earth passed the plane of the ring in April, going south. On September 3 the sun passed the plane going south. On September 13 the earth passed back north, and on January 19, 1849, the earth once more went south with the sun. Therefore between April and September 3, the earth and sun were on opposite sides of the ring. This was again the case between September 13 and January 19.

Bond assumed in all his observations that what he saw was the sunlit edge of the ring. He was not therefore forced to any unusual method to explain its visibility. It takes but a moment on a good night at present with the 40-inch telescope to see that in reality what is visible is not the edge but the extremely oblique surface of the ring itself. This was especially so in the observations in the first part of July, when the minor axis of the ring was about 2″. His explanation therefore cannot be the true one.

Bond's explanations of the bright markings, condensations, or knots, seen on the ring during part of its "invisibility" is an ingenious one, and is seemingly confirmed by his measures. Though his explanation may in part have something to do with the phenomenon, it is not entirely satisfactory. The thickness of these condensations, even allowing for irradiation, is entirely too great to assume that they are due to the edge of the ring, which must be much less than 0″.1 in width.

The circumstances of the disappearances in 1861–62 were very favorable for observation. Advantage was taken of the opportunity to study this interesting phase of the ring at Greenwich by Mr. Carpenter with the 12-inch refractor, and at Pulkowa by Otto Struve with the 15-inch. At this time when the ring was theoretically invisible it could readily be seen. Luminous appendages were visible on it both at Greenwich and Pulkowa, when it was not illuminated by direct sunlight. Since then, during an interval of 45 years, no favorable opportunity has presented itself to reobserve the phenomena seen by the Greenwich and Pulkowa observers in 1861–62. The disappearances of 1878 and 1891 occurred under very unfavorable conditions, as the planet was too near the sun in each case to be satisfactorily observed. In the last case *Saturn* rose about two

hours before the sun. In both those years there was only one disappearance and reappearance.

In the present year—1907—there has been a repetition of the disappearances and reappearances of 1861–62. After 1891 the sun and the earth were on the north side of the ring.

The following information concerning the present disappearances is due to Professor Hermann Struve (*Proceedings of the Astronomical Society of the Pacific*, **19**, 125–35, June, 1907).

April 17, 1907: The earth passed through the plane of the ring to the south side, leaving the sun on the north side. This disappearance could not be seen from the earth, the planet at that time being lost in the sun's rays. From this date until July 26 the ring was supposed to be invisible, as no direct sunlight reached its earthward surface. On July 26 the sun also passed to the south and the ring again became bright. This condition continued until October 4, when the earth once more passed to the north and will remain on the dark side of the ring until January 7, 1908, when it will again pass to the south and the sunlit side of the ring will be visible for the next fifteen years.

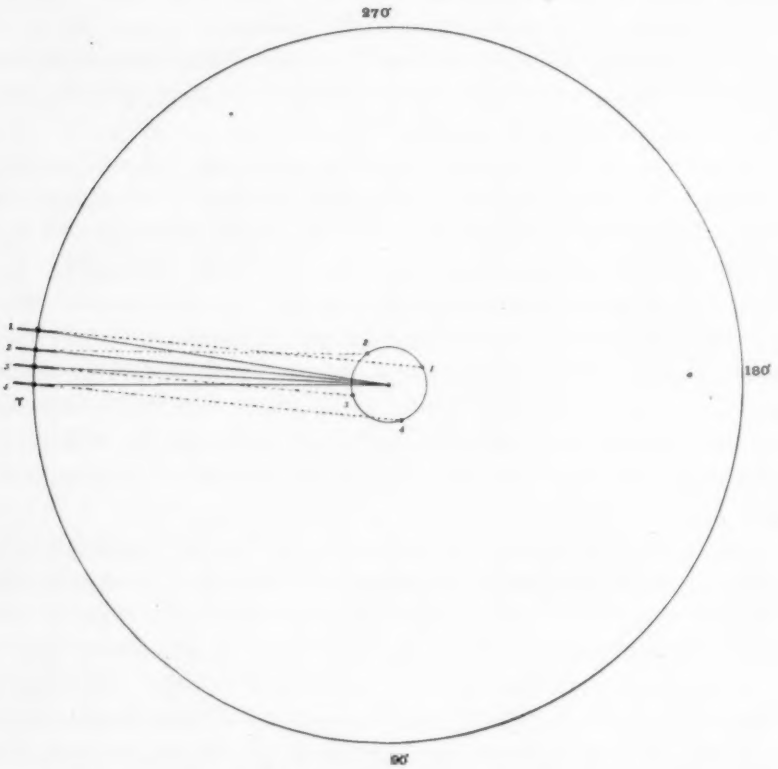
On account of the circumstances of the disappearances and the fairly favorable position of the planet, this was the first opportunity for such observations to be made with the great telescopes of the world, for in the past 45 years they have all come into existence.

When I examined *Saturn* on July 2 the entire surface of the ring was distinctly visible. No direct sunlight was then falling on its earthward surface. On each ansa were two conspicuous luminous places or condensations. These were symmetrical with respect to the ball. In appearance they were very nebulous, the light of the ring and the condensations being of a pale ashy or nebulous color. The positions of these luminous appearances were measured with the micrometer. Repeated measures have not shown any change in their positions.

On July 26 the sun passed the plane going south, and until October 4 it was shining on the visible surface of the ring. During this period the ring was bright and linear and no irregularities were visible upon it where the condensations had been seen.

On October 4 the earth passed back to the shadow side of the

ring, and for some days thereafter the ring was perfectly linear. The apparent condensations had disappeared at a time when they should have been best seen if they were real masses on the ring system. On



The diagram shows the relation of the orbit of *Saturn* and the earth drawn to scale. I have indicated the positions of the earth and *Saturn* and his ring at the critical times for the disappearances, etc., in 1907. 1–1 are the positions of the earth and *Saturn* on April 17; 2–2 the same for July 26; 3–3 the same for October 4; 4–4 the same for January 7. It is hardly necessary to call attention to the fact that between the positions 1 and 2 the earth is on the shadow side of the ring, and from 2 to 3 it is on the sunlit side, while from 3 to 4 it is once more on the shadow side.

October 13 they had again appeared, but were only very slightly luminous thickenings on the ring. After that they became more and more conspicuous as the ring opened out by the elevation of the earth above its north surface. This amounted to nearly a degree

in the latter part of November, at which time the sun was some 2° south of the plane.

I have assumed the following interpretation of the phenomena of the bright condensations and of the visibility of the ring. What we really saw in July, and in October and November, when the sun was on the opposite side of the ring to us, was the feebly luminous surface of the ring itself at a very oblique angle—where the angular diameter was reduced to a second of arc or less; at the observations in July it was 2″ in diameter. As this surface was visible without the aid of the direct sunlight, the natural assumption would be that the ring is self-luminous. Its physical constitution, however, forbids this supposition. It is well known that the crape ring is transparent and that it transmits sufficient sunlight to make a satellite visible while in its shadow. This was shown at the eclipse of *Japetus* on November 1, 1889, when the satellite was seen throughout the entire extent of the shadow of the crape ring, which at most cut down the brightness about one magnitude. The ball of the planet is readily seen through this ring when the rings are opened out wide. This transparency, and the duskiness of the ring on the sky, are undoubtedly due to a scarcity of the particles which compose it. The other rings are bright because they are made up of a vastly greater number of small bodies to reflect the sunlight. That these rings do not transmit a great amount of light was proved at the eclipse of *Japetus* already mentioned, for when the satellite entered the shadow of the bright rings it completely disappeared. This does not mean, however, that the rings are entirely opaque to the sun's light. Though they are translucent, they are not transparent in the ordinary sense of the word, for the planet cannot be seen through them where they cross the ball.

This brings us to a probable explanation of the phenomena of the condensations which have been visible on the dark side of the rings. Knowing that the crape ring is transparent, if we were to look at its under side—the opposite side from the sun—at an oblique angle we should still see it luminous by the reflection of the sunlight in our direction from the small bodies composing it. The illumination would be nearly as strong as when seen from the sunward side. From the extreme thinness of the rings, which must be greatly under 100 miles (60 km), and more probably less than 50 miles, the par-

ticles cannot form an impenetrable screen to the light of the sun. That is, the sunlight will sift through among them, and by diffusion and inter-reflection and scattering will make the rings visible from the dark side. We should therefore expect to see the entire surface of the rings at this time by the percolation, scattering, and reflection of the sunlight through them. One might expect under these conditions that the brighter portions of the ring would appear dark when so seen by cutting out more of the sunlight through a greater number of particles. This, however, up to a certain point of density would not be so; it would in reality be just the reverse. In the case of the crape ring it would appear faint—as it does always—because of the fewer particles to reflect the sunlight. Where they are more densely packed, as in the bright rings, there would be a relatively greater amount of scattering, reflection, and diffusion of the light and they would therefore appear relatively bright.

It is apparent to any observer of *Saturn* ordinarily, with a telescope of sufficient power, that the outer one-fourth of the inner bright ring is much the brightest part of the entire ring and ball system; the inner portion of that ring being of the same brightness as the outer ring which is uniformly illuminated. Let us therefore see where these condensations fall upon the projection of the rings. I have repeatedly measured with the micrometer their positions since the first of July.

It is perhaps appropriate here to give the dimensions of the ring and ball system of *Saturn* as measured by the writer in 1894–95 and with them the positions of the condensations as they may be useful to others in connection with the problem. They are all reduced to the mean distance of *Saturn* from the sun = 9.5389. (See *Monthly Notices*, **56**, 171, 1896.)

Equatorial diameter of *Saturn*	17".800	Radius	8".900
Outer diameter of outer ring	40.108		20.054
Inner diameter of outer ring	35.046		17.523
Center of Cassini division	34.517		17.258
Outer diameter of inner ring	33.988		16.994
Inner diameter of inner ring	25.647		12.823
Inner diameter of crape ring	20.528		10.264
Width of Cassini division	0.529		
Inner condensation preceding	2.675 from the limb or		11".575 from center
Outer condensation preceding	7.457 from the limb or		16.357 from center
Inner condensation following	2.737 from the limb or		11.637 from center
Outer condensation following	7.420 from the limb or		16.320 from center

Though it does not enter into the present problem, the measured polar diameter of *Saturn* was 16".241.

A glance at the figures will show that the outer condensations fall on the brightest part of the inner bright ring—the outer one-fourth of which, as I have already said, is very much the brightest part of the entire system of *Saturn*. The inner condensations apparently fall on the crape ring. In reality the ring system is seen almost on edge, so that the visible surface is very oblique. The crape ring may have nothing to do with the explanation of the luminous appendages for reasons previously given. But the projection of the bright part of the inner bright ring would fall in the same direction as the crape ring. It would seem therefore that this bright region of the ring is really accountable for both condensations. It is clearly so in the case of the outer ones. Why the space between the bright places should be almost discontinuous does not yet appear quite clear. It may be due to the curvature of the ring at this point where the sunlight might be less effective in diffusion and reflection by the greater depth of the ring there in the line of sight.

On December 12, 1907, I made the following additional measures of the condensations. The values are reduced to the mean distance of *Saturn* from the sun:

Length of outer condensation	2".28
Space between the condensations	2.30

The measures of the positions of the condensations given in the table refer to their centers. Applying the above measures and those in the table, we have:

Distance from the center of *Saturn* to the outer edge of the distant condensations	17".50
Distance to outer edge of Cassini division . .	17.52
Distance from the center of *Saturn* to extreme end of inner condensations	12.92
Distance to outer edge of crape ring	12.82

The accordance of the above measures has suggested another explanation of the phenomena of the condensations.

If the Cassini division is not free of particles, the sunlight shining

through among them would produce a luminous effect, as seen from the dark side of the ring, which would be represented by the position of the outer condensations. At the same time a similar illumination of the crape ring would produce the effect of the inner condensations.

Of course this is opposed to the generally accepted theory of the Cassini division, which considers it to be a zone in which no particles can exist owing to the action of certain of the satellites. This assumption would require that the Cassini division should be as closely filled with particles as is the crape ring, because the two pairs of condensations have been of equal brightness.

Though the condensations appear decidedly thicker than the projection of the ring in general, I think it is due to an irradiation effect, and that they are not any thicker than the trace of the ring on the sky: first, because they entirely disappear when the ring is really on edge—at a time when they should be most conspicuous; second, because in making drawings of the planet and ring as they now appear, I have reproduced the exact appearance by simply darkening the ring around the positions of the condensations without changing at all its outline. The eye is therefore deceived by the relative brightness of the condensations.

In the drawing of *Saturn* (Fig. 1, Plate V) I have endeavored to reproduce as exactlv as possible the appearance of the ring and condensations as seen on December 12, 1907, at $17^h 0^m$ G. M. T. The same appearance, essentially, can be produced, as I have said, by leaving the excessively narrow elliptical outline of the ring unchanged, and by simply darkening it around the positions of the condensations. I have sent drawings of this latter kind in a paper to the Royal Astronomical Society, which I believe are the correct representation when the drawing is seen from the proper distance.

The present drawing should be looked at from a distance of about 3 feet to get the correct scale and appearance as seen in the 40-inch telescope with a power of 460 diameters.

Fig. 2 of Plate V is made from the measures given in this paper and represents a view of the system of *Saturn* seen from a position at right angles to the plane of the rings. The Lines *AA* and *BB* indicate where the condensations would fall by projection on the ring system.

PLATE V

South

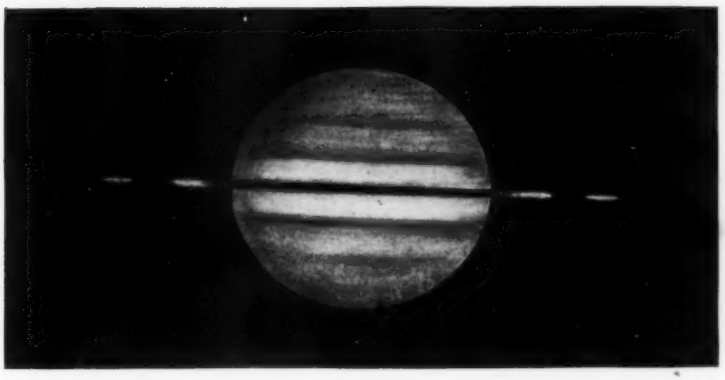


FIG. 1

1907 DECEMBER 12, $11^h 30^m$ G. M. T.

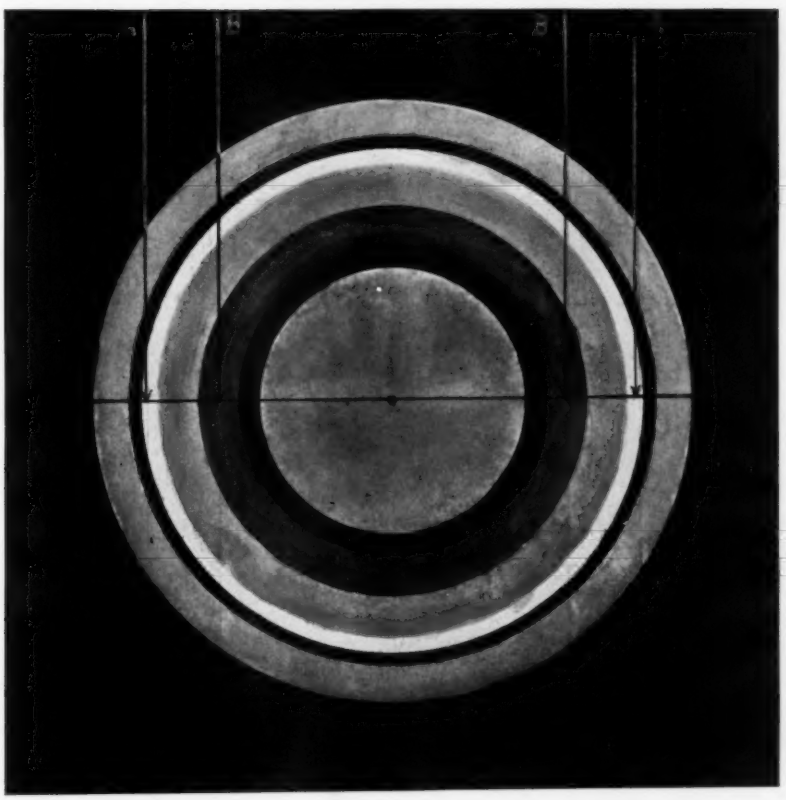


FIG. 2

DIAGRAM OF THE RING SYSTEM OF *SATURN* SHOWING THE POSITIONS OF THE CENTERS OF THE CONDENSATIONS (*AA*, *BB*)

I will briefly describe the appearance of these luminous appendages as they were seen in the 40-inch telescope of the Yerkes Observatory (July, October, and November).

The full extent of the ring was seen as a slender line of light on each side of the planet. Symmetrically on these, both preceding and following, were two places of greater luminosity. The outer ones were elongated in the direction of the planet and were approximately $\frac{1}{2}'' \times 2''$. They were ill defined and more or less diffused, and seemingly were thicker than the ring. Beyond them the ring was very faint, but its entire length was seen. Between them and the ball were the inner condensations, which were approximately of equal brightness with the outer ones. These last, however, joined up to the ball with scarcely any lessening of brightness. Between the outer and inner condensations the ring was very faint but continuous. The condensations were quite bright and noticeable, but with a pale nebulous light. Frequent comparisons showed that they were decidedly brighter than either *Mimas*, *Enceladus*, or *Tethys* when these satellites were close to the condensations. Where the ring crossed the ball, its trace has not appeared black, and this is consistent with the supposition of the sunlight being transmitted through the ring.

The important fact clearly brought out at this apparition of *Saturn* is that the bright rings are not opaque to the light of the sun—and this is really what we should expect from the nature of their constitution, as shown by the theory of Clerk Maxwell and the spectroscopic results of Keeler.

During the present observations the ring was not lost entirely when its plane passed through the earth; though at the critical period of passing exactly the plane, it may have been invisible.

The question of the thickness of the ring again comes up at this time, for the opportunity has never been so good for the determination of this quantity. The favorable position of the planet and the powerful telescopes that are in use now would have greater weight than all the previous observations. On October 4, from $14^h\,30^m$ to $16^h\,0^m$ G. M. T., the ring was visible as a faint thin thread of light very difficult to see. The air was unsteady, and later, $17^h\,40^m$ G. M. T., I could not see the ring. This latter fact, however, I attributed to the seeing having become worse. On the following night, October 5, $16^h\,0^m$

G.M.T., it was distinctly visible. Whether it disappeared in the interval will require observations made elsewhere to decide. This may also be said of the interval closely preceding the observation of October 4. That the ring entirely disappeared is probable, for at no time during the period of its supposed disappearance could I see any trace of the sunlit edge, which should have been visible as a bright rim if the ring is of sufficient thickness to be seen exactly on edge.

YERKES OBSERVATORY
December 1, 1907

PRELIMINARY CATALOGUE OF LINES AFFECTED IN SUN-SPOTS[1]

REGION λ 4000 TO λ 4500

By WALTER S. ADAMS

INTRODUCTORY NOTE

One of the co-operative investigations set on foot by the International Union for Co-operation in Solar Research was the detailed visual study of the lines affected in sun-spots. The committee in charge of this work concluded that the simplest way to detect possible changes of intensity would be to compare the observed spot lines with the same lines as recorded in a map of the spot spectrum. The preparation of such a map from visual observations would obviously entail much time and labor. For this reason it seemed desirable to make use of the photographs of spot spectra obtained with the Snow telescope at Mount Wilson. Accordingly, a preliminary map was prepared and placed in the hands of the observers taking part in this work. The present paper is the first of a series which will contain a preliminary catalogue of the lines affected on the original negatives, and should prove of service in connection with the map.[2] Since the intensities in the catalogue are mean values, derived from the discussion of several negatives, they naturally possess greater weight than

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 22.

[2] It is perhaps desirable to emphasize the fact that in our previous publications on the spot spectrum we have made no attempt to give an exhaustive list of the lines affected in sun-spots for any region of the spectrum, but have treated merely some of the more prominent cases of strengthened and weakened lines. As an illustration of this it may be mentioned that in the region $H\beta$ to D a preliminary investigation indicates rather more than 225 lines which are weakened in spots. In a recent study of the same region Mr. Nagaraja of the Kodaikanal Observatory has given a list of 167 weakened lines (*Astrophysical Journal*, **26**, 143, 1907). In this connection it may also be well to state that in our previous discussion of the weakened lines in the sun-spot spectrum on the temperature basis (*ibid.*, **24**, 185, 1906), we have by no means maintained that all the weakened lines are spark lines. On the other hand, so far as our experience goes, it seems to be true without marked exception in the part of the spectrum extending from the red to λ 4000 that all spark lines are weakened. Mr. Nagaraja gives five lines in the region discussed by him which he considers exceptions to this rule. Of the first two of these lines, λ 5169.07 and λ 5169.22, it is the latter

estimates made directly from the map. It is expected that the detailed results from the individual plates will be published later, and it is also hoped that the preliminary map may ultimately be replaced by a more perfect one.

Although the instrument with which the negatives have been obtained, and the procedure followed in making the exposures have been described previously, it may be convenient for the purposes of reference to allude to them here. The spectrograph used was of the Littrow or auto-collimation type with a focal length of 18 feet (5.5 m) and having a 4-inch (10.2 cm) grating with 14,438 lines to the inch (570 lines to the mm). The photographs have all been made in the second order, which gives a linear scale of about 1 mm = 1.5 Å. The spectrograph has been used in conjunction with the Snow telescope, the concave mirror of which forms a solar image about 6.7 inches (17.0 cm) in diameter on the slit. During the exposure of the photographic plate to the spectrum of the spot the light from the photosphere is excluded from the slit, but at the conclusion of this exposure the ordinary solar spectrum is photographed on either side for purposes of comparison. This is readily done by means of an occulting bar which moves across the slit and has an opening of variable size which may be adjusted to the size of the spot under observation. The exposures are timed to give as nearly as possible the same intensity to the continuous spectrum of the spot and of the comparison spectrum. The ratio of the two exposures varies, of course, with the definition of the solar image, the transparency of the sky, and the size and blackness of the spot, as well as the wave-length of the region photographed. Under average conditions at λ 5500 the spot requires about six times as long as the comparison spectrum, while at λ 4000 this ratio increases to about ten or eleven.

The present paper contains a list of the lines affected in sun-spots for the region λ 4000 to λ 4500. It will be followed by other lists giving

which is the spark line, and it is decidedly weakened in spots; the former, on the other hand, is strengthened, and unless the dispersion of the instrument is sufficient to separate the two lines, it might well appear that the blend is not affected. The third line, λ 5188.87, seems to be distinctly weakened on our plates. The fourth and fifth lines, λ 5502.9 and λ 5621.7, either are not represented in the solar spectrum, or the lines are so faint (not above ooo on Rowland's scale) that conclusions can hardly be drawn as to their behavior.

the results obtained by one or both of us in other parts of the spectrum. Our series of photographs in the ultra-violet may not be completed for some time, and for this reason the present list begins at λ 4000.

The tables are of the same general character as those given by us in previous publications. The intensities are based upon Rowland's scale, and in the few instances in which his values for individual lines seem to need modification notes to this effect are added in the margin. For purposes of identification we have compared our list with the tables of the wave-lengths of arc lines by Hasselberg, and the "enhanced" line tables of Lockyer, the wave-lengths given in the marginal notes being from these sources. In general, only the more obvious identifications are included, and no attempt has been made to present alternative identifications unless they seem to be of special significance as regards the behavior of the lines in the spot spectrum. An extended discussion of this sort belongs rather to a detailed analysis of the results than to the catalogue proper, and we shall hope to enter into this subject farther in a concluding paper.

GEORGE E. HALE
WALTER S. ADAMS

The following is a list of the negatives employed in obtaining the results given in this paper. All of the plates were secured by Mr. Ellerman except L 128, which was taken by the writer.

TABLE I

Plate	Date	Greenwich Spot Number
L 76	1906, June 29	5898
L 77	June 30	5898
L 88	July 2	5898
L 82	July 2	5898
L 83	July 2	5898
L 84	July 2	5898
L 92	July 9	5898
L 94	July 30	5944
L 95	July 31	5944
L 101	Aug. 2	5944
L 128	1907, June 22	6205
L 134	July 19	....

In the case of plate L 134 the Greenwich spot number has not as yet been published.

TABLE II

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4000.61	*Fe*	2	2–3	3	
4001.32	*Mn*, —	3	2	4	
4003.08	—	2	1–2	6	
4003.91	*Ce–Fe–Ti*	3	3–4	3	Widened
4005.86	*V*	3	2–3	3	Spark line of *V*
4006.90	—	2	2–3	3	
06.98	—	1			
4009.02	—	2	6	7	
09.08	*Ti*	3			
4009.29	—	1	0–1	3	
4009.81	*Ti*	1	5–6	3	Much widened
09.86	*Fe*	3			
4010.33	*Ce–Fe*	1	1–2	3	
4010.74	—	3	2–3	3	Rowland's intensity too high: 2 better
4011.56	*Fe*	3	3–4	3	
4012.54	*Ti, Ce*	4	3–4	6	Narrow. Spark lines of *Ti* and *Cr*
12.63	*Cr*	0			
4013.80	*Ti–Fe*	3	3–4	3	
4015.53	—	0	0–1	3	Hasselberg gives *Ti* 4015.56
4015.76	—	3	2	3	Narrow. Spark line of *Ni*
4017.93	*Ti*	0	0–1	3	
4018.23	*Mn*	3	9	4	Widened
18.27	*Mn*	4			
4019.20	*Ni–Ce*	1	1–2	3	Widened
4019.45	*Co*	0	0–1	7	Rowland's intensity too high: 00 better
4020.34	—	1	2	3	
20.42	—	2			
4020.55	*Sc*	1	3	8	
20.64	*Fe*	1			
4021.06	*Nd–Co*	3	3–4	8	
4022.02	*Ti–Fe–V*	5 d?	6	3	
4022.37	*Fe*	1	1–2	4	
4023.53	*V, Co*	3	2–3	8	Spark line of *Co*
4023.83	*Sc*	2	3	7	
4024.73	*Ti*	3	4	3	
4025.16	*Cr*	0	4	7	Widened to violet. Spark line of *Ti*
25.29	*Ti–Ce*	3			
4026.32	*Cr*	0	1	8	
4026.58	*Mn*	2 N	4	3	
26.69	*Ti*	1			
4027.19	*Co*	1	3	8	
27.25	*Cr*	0			
4027.82	—	1	0–1	7	
4028.50	*Ti–Ce*	4	3	8	Spark line of *Ti*
4030.34	*Fe*	2	2–3	3	
4030.65	*Nd–Fe–Ti*	5	5–6	3	
4030.88	*Mn*	10 d?	11	4	
30.95					
4033.22	*Mn*	8 d?	10	3	Widened
33.34	*Fe?*	1			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4034.64	*Mn*	6 d	8	3	Widened, hazy
4036.52	—	0	0–1	8	
4036.92	*V*, —	1	0–1	7	
4037.27	—	2	2	8	Very hazy. Rowland's intensity too high: 1 better
4038.94	—	2	2–3	3	
4040.09	*Fe*	1	1–2	3	
4040.24	*Fe?*	2	1–2	3	
4040.79	*Fe*	3	4	4	Hazy. Rowland's intensity too high: 2 better
4041.43	*Fe*	3	9	5	Widened
41.52	*Mn*	5			
4044.06	*Fe*	3	4	6	
44.14	—	2			
4045.54	*Co*	5	5–6	3	Difficult: in shade of following line
4045.98	*Fe*	3o	32	6	Probably slightly strengthened
4047.82	*Y*	0 N	1–2	7	
47.96	—	0 N			
4048.82	*Zr*	1	7	6	Widened
48.91	*Mn–Cr*	5			
4050.83	*Fe*	2	1–2	3	
4051.49	*Cr–V*	0 Nd?	0–1	3	
4052.60	*Mn, Fe*	2	4	3	Rowland's intensity too high: 4 better for total
52.65	—	3			
4053.98	*Cr–Fe–Ti*	3	2–3	7	
4054.59	*Zn*	0	1–2	3	Strengthened to red
54.71	*Sc*	00 N			
4054.96	*Fe*	2	4	6	
55.02	*Fe*	3			
4055.70	*Mn*	6	7	6	
4056.50	*Fe*	1	2	3	
56.60	—	0			
4057.37	*Co*	1 N	4–5	4	Not fully separated from following line
57.50	*Fe*	3			
4057.67	—	7	5	4	
4059.08	*Mn*	3	4	6	
4059.54	*Mn*	1 Nd?	2	3	Widened to red
59.65	—	0			
4059.87	*Fe*	2	1–2	7	
4060.42	*Ti*	1	2	8	
4060.64	—	0	00	3	Nearly obliterated
4060.92	—	0	0–1	3	
4061.78	*Mn*	2 Nd	2–3	6	Fringe on violet side
4062.10	—	2	1–2	3	
4062.60	*Fe*	5	5–6	5	Widened
4064.36	*Ti*	1	2	5	
4065.24	*Mn–Ti*	2 d?	3	7	
4066.52	*Co*	2	3	7	
4067.14	*Cr–Fe*	5	5–6	3	
4067.43	*Fe*	3	4–5	6	
4068.14	*Fe–Mn*	6	7	6	Very hazy, widened
4068.69	*Co*	0	0–1	3	
4070.43	*Mn*	3	4–5	7	Much widened

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4073.92	*Ce, Fe*	4	5	4	
4075.26	*— Nd*	2 N	1–2	6	Rowland's intensity too high: 1 better
4076.10	*Fe*	3	2–3	7	
4077.88	*Sr*	8	8	6	Winged
4078.52	*Zr–Fe*	4	8	7	
78.63	*Ti*	3			
4079.34	*Fe*	2	6	4	Widened
79.39	*Mn*	3			
4079.57	*Mn*	3	3–4	3	
4080.00	*Fe*	3	4	7	
4080.37	*Fe, Nd, Cr*	3	3–4	3	
4081.38	*Zr, Ce*	0	2	4	
81.42	—	1			
4082.26	*Fe*	2	2–3	3	
4082.59	*Sc–Fe–Ti*	3	4	8	
4083.10	*V–Mn*	4	5	7	Widened
4083.72	*Fe*	2	7	4	
83.78	*Mn, Y*	4			
4084.65	*Fe*	5	5	7	Perhaps winged
4085.47	*Fe*	4	5–6	7	Widened
4086.47	*Co—*	3 d?	4	7	Much widened
4086.86	*La*	1	1–2	3	
4089.37	*Fe*	3	4	6	
4090.73	*V*	1	2	8	
4091.11	*Ce —*	3	3–4	4	
4091.71	*Fe*	3	3–4	6	
4092.82	*V, Ca*	3 d?	4–5	8	
4095.09	*Ca?*	4	5	8	
4095.42	*Mn*	0	0	6	
95.51	—	0			
4095.63	*V*	0	1	6	
4096.37	—	1	1–2	6	
4097.24	*Fe*	3	3	7	Very broad and hazy
4097.61	—	000	0	3	
4097.81	—	0	0–1	6	
4098.12	—	0	0–1	3	Seen as fringe on following line
4098.34	*Fe*	5	4–5	6	
4098.69	—	4	7	7	
98.75	*—, Co?*	2			
4099.21	—	0	1–2	6	Very broad
99.33	*Ti*	00			
4099.94	*V*	2	4	8	
4100.32	*Fe*	2	1–2	6	
4100.50	—	0	1	3	
4100.90	*Fe*	4	4–5	5	
4102.00	*H, In*	40 N	20	7	*H δ* is both narrowed and weakened
4102.32	*V*	0	1	7	
4103.10	*Si, Mn*	5	6	4	
4104.91	*Co, V*	00	0	7	
4105.32	*V*	2	4	8	Broad
4105.98	—	000	00	3	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4106.42	*Fe*	2	3–4	7	
4106.58	*Fe*	2	1–2	6	
4106.8			0	3	Perhaps a blend of two faint solar lines
4107.65	*Ce–Fe*	5	6	4	Widened, hazy
4108.29	—	1	1–2	4	
4108.69	—	2	3	7	
4109.22	*Fe*	3	3–4	5	Narrow
4109.90	*V*	2	7	7	Much widened
09.95	*Fe*	3			
4111.15	—	1	00	3	Nearly obliterated
4111.51	*Ce?*	1	1–2	4	
4111.94	*V*	4	6	8	Very broad
4112.48	*Fe*	2	3	7	Much widened
4112.87	*Ti*	1	2	8	
4113.07	—	1	3	8	Narrow
13.12	*Fe*	3			
4113.68	—	000 Nd?	1	7	Broad patch
4114.27	—	00 d	0–1	3	
4114.61	*Fe*	4	5	6	Widened
4115.33	*V*	3	4–5	8	
4116.63	*V*	1	3–4	8	
16.71	*V, Fe?*	0			
4116.97	*Nd?*	00	0	3	Seen as fringe on 4116.86
4117.11	—	0	0–1	3	
4117.59	—	000	0–1	3	Broad patch
4118.01	—	2	3	7	Widened
4118.31	*V*	0	0–1	7	
4118.71	*Fe*	5	6	5	
4118.93	*Co*	4	7	5	
19.05	*Fe*	2			
4120.78	—	0	1	3	Broad patch. Hasselberg gives *V* [4120.69
4121.48	*Cr–Co*	6 d?	7	5	
4121.96	*Fe, Cr*	3	3–4	5	
4122.82	—	1	1–2	3	
4123.38	*La*	1	0	5	
4123.54	*Cr*	0	3–4	8	
23.66	*Ce, V–Mn*	1			
23.71	*Ti*	000			
4123.91	*Fe*	5	4	4	Rowland's intensity too high: 4 better
4124.64	—	0	0–1	3	
4125.53	—	000	0	3	
4125.78	*Fe*	3	3	5	Narrow
25.85	—	1			
4126.20	—	000	5	5	
26.34	*V–Fe*	4			
4126.67	*Cr*	2	3	7	Rowland's intensity too high: 1 better
4127.01	—	1	2	7	
27.07	*Cr*	00			
4128.25	*Ce–V, —*	6 d	8	6	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4128.46	—	∞	0	3	
4128.89	—	2	0	7	Nearly obliterated; fringe on red side probably due to 4129.13
4129.34	*Ce* —	3	3–4	6	
4129.62	—	2	1–2	7	
4130.11	—	0	3	7	
30.20	*Fe*	2			
4130.60	—	0	3	6	
30.80	*Ba*	2			
4131.27	*Ce, Mn*	1	2	4	Hasselberg gives *V* 4131.32
4131.51	*Cr*	0	1	7	
4132.10	*V*	2	14	6	Widened to violet
32.24	*Fe–Co*	10			
4132.69	—	3	2	7	
4133.06	*Fe*	4	4–5	5	
4133.76	*Fe*	2	0	7	Rowland's intensity too high: 1 better. Fringe to violet
4134.49	*Fe?*	3	7–8	6	
34.59	*Fe?*	3			
4135.84	—	∞	1–2	7	
35.92	*Zr*	0			
4136.68	*Fe*	4	5	7	
4137.16	*Fe*	6	7	4	Spark line of *Mn* falls here
4137.43	*Ti, Mn*	0 Nd?	3–4	7	Widened to violet
37.57	—	2			
4138.13	—	0	0–1	3	Broad
4138.52	—	0 N	6	8	
4139.52	—	∞	1	4	Broad patch. Hasselberg gives *V* 4139.39
39.61	—	∞∞			
4140.09	*Fe*	6	6–7	3	
4140.56	—, *Fe?*	3	3–4	7	Much widened, perhaps winged
4140.91	—	0	0–1	3	
4142.02	*Fe*	4	4–5	3	Widened
4143.57	*Fe*	4	5–6	5	Narrowed in spot
43.66	—, *Mo*	2			
4144.04	*Fe*	15	13	6	Narrowed in spot
4146.22	*Fe*	3	3	6	Fringe on red side
4146.84	—	0 N	1	7	Broad
4147.14	—	2	1	7	
4147.50	—	2	1–2	3	Rowland's intensity too high: 1 [better
4147.84	*Fe*	4	6–7	7	
4148.55	—	∞	0	3	
4149.53	*Fe*	4	5	6	Widened
4149.92	—	2	3	7	
4150.41	—	4	4–5	7	Rowland's intensity too high: 3 [better
4150.61	*Co*	1	0	7	
4151.13	*Ce–Zr, Ti*	1	1–2	6	
4152.24	—	1	4–5	5	
52.34	*Fe*	3			
4152.69	*C?*	∞	0–1	3	Hasselberg gives *V* 4152.81
52.76	*Zr*	∞			
4152.93	*Cr, La*	0	00–0	3	

TALBE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4153.22	*Cr*	∞	0–1	7	
4153.78	*Co*	0	0–1	3	
4153.97	*Cr*	1	6	6	
54.07	*Fe*	4			
4154.67	*Fe*	4	4–5	7	Widened
4154.98	*Fe*	4	4–5	5	
4155.21	—	∞	0	2	
4155.68	—	∞	1	3	Broad patch
55.80	—	∞			
4156.07	—	1	0–1	3	
4156.39	*Zr*	1	2	4	
56.47	—	3			
4157.95	*Fe*	5	5–6	3	
4158.54	*C?*	0	1	7	
58.59	*C?*	∞			
4159.35	—	5	4	7	
4159.80	*Ti*	0	1	4	
4160.53	—	2	3	7	Widened. Hasselberg gives *V* 4160.57
4161.37	*Zr* —	2	1–2	3	
4161.68	—	4	3–4	7	Widened. Spark line of *Ti* falls here
4161.96	*Sr*	1	∞	7	Nearly obliterated. Spark line of *Sr*
4162.28	—	∞ N	0	3	
4162.62	*C*, —	1 N	0–1	3	
4162.82	*Ce*, *C*	1 N	0–1	3	
4163.07	—	∞	1	6	
63.14	—	∞∞			
4163.64	—	0 d	0–1	3	
4163.82	*Cr–Ti*, —	4	3–4	4	Spark line of *Ti*
4164.80	—	0	2	7	Hasselberg gives *Ti* 4164.80
64.94	—	0			
4165.28	—	0	1	7	
4165.55	*C*, *Fe*	3 d	2–3	3	Narrow
4165.76	—, *Ce*	1	0–1	7	
4166.16	*Ba*	0	1–2	6	
66.26	—	∞			
4166.36	—	∞	2	6	Hasselberg gives *Ti* 4166.45
66.46	—	0			
4167.44	—	8	6	6	
4168.02	*Ce–Fe*	2	4–5	6	
68.13	*Ni*, *C*	2			
4168.63	—	∞ N	3	7	Strengthening due to 4168.63
68.78	—	2			
4169.11	—	2	2–3	3	
4169.93	—	2	2–3	3	
4171.07	*Fe*	4	4–5	3	
4171.85	*C*, *Fe?*	2	2–3	6	
4172.07	*Ti*, *Fe*	2	1–2	6	Spark line of *Ti*
4172.21	*Al*	1	4–5	7	
72.30	*Fe–Ce*	2			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4172.80	—	2	6	5	Weakened to violet, probably strengthened to red
72.92	*Fe*	4			
4173.14	—	1	0–1	6	
4173.62	—	3	4–5	7	Spark line of *Fe*
73.71	—	3			Spark line of *Ti*
4174.10	*Fe*	3	4	6	Weak to red. Spark line of *Ti* at 4174.20. Hasselberg gives *V* 4174.18
74.24	—	0			
4174.97	*Cr*	0	5–6	7	
75.08	*Fe*	4			
4175.29	—	1 N	0	7	
4175.81	*Fe*	5	5–6	3	
4178.22	—	2	1	7	
4179.02	—	3	2	7	Spark line of *Fe*
4179.54	*V*, —	3 d?	3–4	7	Widened
4180.56	—	1	1–2	6	
4181.35	—	0	0–1	3	
4181.92	*Fe*	5	5–6	4	
4182.14	—	2	1–2	7	Narrow
4182.92	—	2	1–2	4	Narrow
4183.17	—	1	0–1	5	
4183.48	*Zr*	1 N	2	7	Weak to red. Spark line of *V* at 4183.60
83.62	—	2 N			
4184.16	—	4	3	7	Rowland's intensity too high: 3 better
4184.47	—	2	1–2	7	Narrow. Spark line of *Ti* at 4184.40
4185.06	*Fe*, *Cr*	4	5–6	7	
4186.28	*Ti*	1	2	7	
4186.78	*Ce–Zr*	2 N	1–2	6	
4187.20	*Fe*	6	7	6	
4187.94	*Fe*	5	9	6	
88.02	—	3			
4188.89	—	4	3–4	5	
4189.14	*C*, —	1	2–3	4	
89.26	—	1			
4189.98	*V*	0 Nd?	1	7	Rowland's intensity too high: 00 better
4190.29	*Cr*	0 N	1–2	6	
90.40	*C*	0			
4190.87	*C*, *Co*	1 Nd?	2–3	8	
4191.60	*Fe*	6	7–8	7	Winged
4191.84	*Fe*	3	3–4	6	
4192.56	*C*	00 N	00–0	3	
4192.73	—	2 N	1	7	
4194.89	*C*, —	1	3	6	Very broad
95.01	*Cr*	1			
4195.49	*Fe*	5	5–6	6	
4195.68	—	1	3–4	7	
95.78	*Fe–C*	2			
4197.26	*C*	2	3	7	Widened to red
97.39	*Cr*	0			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4197.81	—	∞	1	6	Hasselberg gives *V* 4197.77
97.90	—	∞			
4198.22	*Fe*	2	2–3	4	
4198.40	—	4	7	4	
98.49	*Fe*	4			
4198.80	*Fe*	3	3–4	6	
4199.27	*Zr–Fe*	5	6	4	Very hazy
4200.04	—	1 N	4	7	
00.15	*Fe*	2			
00.26	*Cr*	∞			
4200.95	*Ti*	1	2	7	
4201.09	*Fe*	3	3–4	4	
4202.20	*Fe*	8	10	6	Winged
4203.62	*Ti*	∞ N	3–4	7	
03.73	*Cr*	2			
4204.88	—	1	2	5	
04.92	—	2			
4205.19	—	1	2	7	Widened
05.24	—	1			
4205.70	—	2	2–3	5	
4206.74	—	1	5	6	Rowland's intensity too low: 5 better for total
06.86	*Fe*	3			
4207.29	*Fe*	3	3–4	7	
4208.77	*Fe*	3	3–4	7	
4209.98	*V*	1	2	7	
4210.49	*Fe*	4	8–9	6	Widened
10.56	—	3			
4211.13	—	3 N	2–3	3	
4211.51	*C–Cr*	0 N	0–1	4	
4211.90	*Mn, C*	0	1	6	Hasselberg gives *Ti* 4211.85
4212.05	*Zr–*	2	1	7	
4213.81	*Fe*	3	3–4	7	Narrow
4215.58	*Fe*	2	8	3	Spark line of *Sr*
15.70	*Sr*	5 d?			
4216.35	*Fe*	3 d?	4–5	7	Widened
4216.76	—	1 N	0–1	3	
4217.72	*La, Fe–Cr*	5 d?	5–6	3	
4218.56	*— Zr*	1 Nd	1–2	6	
4220.51	*Fe*	3	4	6	
4221.63	—	1 N	1	4	
21.74	*Cr*	0			
4222.38	*Fe*	5	6	6	
4223.64	—	1	1–2	3	
23.74	—	1			
4224.34	*Fe*	4	5	3	Hasselberg gives *V* 4224.30
4224.67	*Cr–Fe*	3	4	7	
24.79	*Ti*	∞			
4225.02	—	2 N	1–2	7	Spark line of *Cr*
4225.62	*Fe*	3	3–4	5	
4226.90	*Ca*	20 d?	25	8	Very difficult line. Widened and winged
4228.10	—	1 N	0–1	3	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4229.68	*Fe*	2	2–3	3	Widened to violet
4229.93	*Fe*	3	4	4	Difficult
4232.76	*V*	∞	3–4	9	
32.89	*Fe*	2			
4233.33	*Mn*	4	3	8	Strong spark line of *Fe* falls here
4233.77	*Fe*	6	7	7	
4234.17	*Co, V*	o N	o–1	8	Rowland's intensity too high: ∞ better
4234.71	*Zr*	o N	1	8	Hasselberg gives *V* 4234.70
4235.30	*Mn*	2	6	4	
35.45	*Mn*	3			
4238.19	*Fe*	3	3–4	8	Widened
4239.52	—	2	2–3	8	
4239.89	*Fe, Mn*	3	9	5	
40.01	*Fe*	3			
40.12	—	1			
4240.54	*Fe*	2	4	8	Hasselberg gives *V* 4240.53
40.62	—	1			
4240.87	*Cr*	1	1–2	3	
4241.28	*Fe–Zr*	2	3	8	
4241.68	—	∞ N	1	8	Broad patch
41.87	—	∞ N			
4242.32	—	o	1	4	
4242.54	—	2	3	8	Spark line of *Cr* at 4242.54
42.62	—	2			
4243.98	—	2	1–2	3	Narrow
4245.42	*Fe*	4	8	7	Probably winged
45.52	—	2			
4247.00	*Sc*	5	6	5	
4247.46	—	1	6	4	Hasselberg gives *V* 4247.46
47.59	*Fe*	4			
4247.73	—	o	∞	8	
4248.48	*Ti*	∞	2	8	Widened to violet
48.58	—	1			
4249.10	—	2 N	1–2	8	
4250.29	*Fe*	8	9	5	
4252.39	—	∞	1–2	9	
52.47	*Co*	o			Broad
4252.78	—	o N	1	5	Weak to violet. Spark line of *Cr* at 4252.80
52.92	—	1 N			
4253.16	—	1	o–1	8	Spark line of *Mn*
4253.36	—	1	1–2	3	
4254.50	*Cr*	8	10	7	Widened: probably winged
4255.66	*Fe, Cr*	1	2–3	5	
55.79	—	1 N			
4256.29	*Ti*	o	2–3	4	Very broad
56.37	—	1			
4257.82	*Mn*	2	2–3	6	
4258.32	—	1 N	o–1	3	
4258.48	*Fe*	2	4	9	
4259.46	—	1 Nd?	2	3	Hasselberg gives *V* 4259.46
4260.64	*Fe*	10	9	4	Apparently narrowed in spot

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4261.68	— *Cr*	2	3	7	Widened to red
61.75	*Ti*	oo			
4262.09	—	1	o–1	8	Spark line of *Cr* at 4262.15
62.14	—	1			
4263.29	*Ti, Cr*	2	3	8	
4264.37	*Fe*	3	4	4	
4264.90	*Fe*	2	1–2	3	
4265.83	*Ti*	o	o–1	8	
4266.08	*Mn*	2	2–3	8	
4266.78	—	o	o–1	3	Rowland's intensity too high: oo better
4267.12	*Fe*	3	3–4	7	
4268.78	—	o	3–4	7	Hasselberg gives *V* 4268.78
68.92	*Fe*	2			
4269.45	—	o	ooo	3	Nearly obliterated. Perhaps spark line of *Cr*
4269.90	—	2	3	8	
70.02	—	2 N			
4271.93	*Fe*	15	15	7	Very hazy. Probably narrowed in spot
4272.70	*Ti*, —	1	2	8	
4274.75	*Ti*	2	12	8	Much widened to violet
74.96	*Cr*	7 d?			
4277.15	*V*, —	1 N	1–2	6	
4277.69	—	2 d?	3	8	Much widened
4278.39	*Fe–Ti*	3	3–4	6	Narrow
4279.01	*Ti*, —	1 N	1–2	7	
4279.87	—	2 Nd?	1	3	
4280.56	*Cr*	1	2	8	Broad
4280.94	—	1	o–1	3	
4281.26	*Mn*	2	2–3	6	Narrow
4281.53	*Ti*	o	1–2	8	
4282.13	—	2 N	1–2	3	
4282.56	*Fe*	5	6	3	
4282.86	*Ti*	o	o–1	8	
4283.17	*Ca*	4	5–6	9	
4283.90	—	ooo	o	3	
4284.22	*Mn, V*	o	o–1	3	Seen as fringe on following line
4284.38	—	2 Nd?	1	9	Spark line of *Cr*
4284.99	—	1	o–1	3	Rowland's intensity too high: o better
4285.16	*Ti*, —	2	2–3	8	
4285.52	—	1	3–4	4	
85.60	*Fe*	3			
85.69	—	1			
4286.17	*Ti*, —	2	3–4	8	Narrow
4287.57	*Ti*	1	2	8	
4288.31	*Ti, Fe*	1	2	4	
4288.89	—	(oo N)	1	3	Evident error in Rowland's intensity. Map shows strong line here. Spot intensity is on basis of 2 in Sun

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4289.12	—	1	4–5	8	
89.24	*Ti*	2			
4289.52	*Ca*	4	5	8	
4289.88	*Cr*	5	8	8	*Ti* line probably weakened.
90.08	*Ti*	1			
4290.38	*Ti*	2	1–2	6	Narrow. Spark line of *Ti*
4291.11	*Ti*	3	3–4	8	
4291.28	*Ti*	2	2–3	3	
91.38	—	1			
4291.63	*Fe*	2	3–4	8	Widened
4292.14	*Cr, V*	0	0–1	8	Difficult. Seen as fringe on following line
4292.21	—	1	2	5	Spark line of *Mn* at 4292.35
92.29	—	2			
4292.45	—	2	2–3	7	
4293–19	—	2	4	8	
93.27	—	3			
4294.20	*Ti*	2	9	8	Spark line of *Ti*
94.30	*Fe*	5			
4295.19	—	3 d?	4–5	8	
95.38	—	3 Nd?			
4295.91	*Cr, Ti*	2	3–4	8	Narrow
4296.74	—	3	3	5	Spark line of *Fe* at 4296.72
96.84	*Zr?*	1			
4297.37	—	2	3	5	
97.45	—	2			
4297.68	—	1 N	0–1	5	
4297.91	*Cr, V*	0	0–1	8	
4298.14	*Ti*	1	4	8	
98.20	*Fe*	2			
4298.36	—	1	0–1	3	
4298.83	*Ti*	2	3	8	
4298.97	—	2	1	3	
4299.15	*Ca*	3	4	9	
4299.41	*Ti, Fe*	4	5	3	
4299.80	*Fe, Ti*	2	3	9	
4299.99	—	1 N	0–1	3	
4300.21	*Ti*	3	2–3	9	Spark line of *Ti*. Rowland's intensity too low: 4 better
4300.48	—	1 N	0–1	3	
4300.73	*Ti*	2	3	8	
4300.99	—	1	0–1	7	
4301.16	*Ti*	2	8	8	Weak on red edge; *Ti* line strengthened
01.26	—	4			
01.33	—	1			
4301.90	—	0 Nd?	00–0	3	
4302.08	*Ti*	2	1–2	4	Spark line of *Ti*
4302.69	*Ca*	4	6	9	Probably winged
4303.34	—	2	1	8	Spark line of *Fe*
4303.58	—	1 N	0–1	3	
4303.99	—	2	4	8	
04.10	—	4			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4304.42	—	1	0–1	3	
4304.55	—	1	0–1	3	
4304.73	*Fe*, —	2	1–2	6	
4305.27	—	1	0–1	7	
4305.48	—	1	3–4	5	Spark line of *Sr*
05.61	*Fe,Sr,Ti, Cr*	3			
4306.08	*Ti*	4	5–6	8	
4306.86	—	2	3	8	
07.02	—	2			
4307.91	*Ca*	3	10	8	Violet component probably strengthened, red weakened. Spark line of *Ti* at 4308.10
08.08	*Fe*	6			
4309.06	—	1	2–3	7	
09.20	*Fe*	2			
4309.54	*Fe*	3	3–4	7	
4309.79	—	1	1	5	
09.88	—	1			
4309.99	—	0	1–2	7	Hasselberg gives *V* 4309.95
10.07	—	0			
4310.27	—	2	1	7	
4310.54	—	2	2–3	4	
10.63	—	1			
4310.86	—	2 N	2–3	6	
4311.06	—	1	1–2	6	
11.15	—	1			
4311.61	—	2	2–3	5	Spark line of *Mo* at 4311.71
11.67	—	2			
4312.25	—	2	2	4	
12.31	—	1			
4313.03	*Ti*	3	2–3	7	Spark line of *Ti*
4213.80	—	2 Nd?	1–2	3	
4314.25	*Sc*	3	3–4	7	
4314.96	*Ti*	1	2–3	8	
4315.14	*Ti*	3	8	6	Spark line of *Ti*
15.26	*Fe*	4			
4316.96	*Ti*?	1	0–1	8	Spark line of *Ti*
4318.82	*Ca, Mn*?	4	6	8	Winged. Hasselberg gives *Ti* 4318.83
4320.66	—	0	1–2	7	
20.76	—	00			
4321.12	—	2	1–2	7	Possibly spark line of *Ti*
4321.81	*Ti*	0	1	8	
4323.39	—	2 Nd?	1	5	
4324.01	—	3	2	5	
4324.57	—	2 N	1–2	4	
4325.15	*Sc*	4	6	7	Widened to red
25.31	*Ti, Cr*	1			
4325.94	*Fe*	8	8	6	Apparently narrowed in spot
4326.52	*Ti*	0	1	7	Narrow
4327.27	*Fe*	3	2–3	3	
4328.08	*Fe*	2	2–3	6	Much widened: very hazy
4328.77	—	0 N	00–0	8	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4329.45	—	0 N	0	3	
29.56	—	0 N			
4330.19	*V*	0 N	2	9	
4330.40	—	1	0	7	
4330.57	—	0	00–0	3	Spark line of *Ti* at 4330.50
30.61	—	0			
4330.87	*Ti, Ni*	2	1–2	8	Spark line of *Ti*
4331.81	*Ni*	2	2	7	Very narrow line in spot. Measures show no change
4332.99	*V*	0	2	9	
33.08	—	0			
4335.10	*La*	0	1	7	Broad. Hasselberg gives *Ti* 4334.98
4337.22	*Fe*	5	7	8	Winged
4337.72	*Cr*	3	4–5	8	
4338.08	*Ti*	4	3	9	Spark line of *Ti*
4338.43	*Fe*	1	2	9	
4339.62	*Cr*	4	6	8	
4339.88	*Cr*	3	4	8	
4340.30	*Cr*	0	0–1	7	
4340.63	*H*	20 N	8	8	*Hγ* is both weakened and narrowed
4341.17	*V*	0	2	9	
4341.53	*Ti?*	2	1	8	Spark line of *Ti*
4342.35	—	0	1	3	Broad patch
42.48	—	00			
4343.37	*Cr*	2	4–5	7	
43.43	*Fe*	2			
4343.86	*Fe*	2	2–3	3	
4344.13	—	1 N	0	3	Rowland's intensity too high: 0 better. Spark line of *Mn*
4344.45	*Ti,* —	2	1–2	7	Spark line of *Ti*
4344.67	*Cr*	4	6	8	
4345.05	—	0	00	3	
4345.25	—	00	0–1	3	Broad patch
45.40	—	0000			
4346.28	—	00	00–0	3	Hasselberg gives *Ti* 4346.26
4346.45	—	1	0–1	9	
4346.99	*Cr*	1	1–2	9	Rowland's intensity too high: 0 better
4347.40	*Fe*	1	2	9	
4348.50	—	1 N	0–1	7	
4349.11	*Fe*	2	2–3	3	
4351.00	*Ti*	1	0–1	9	Spark line of *Ti*
4351.22	*Cr*	3	5	8	
4351.93	*Cr*	5	11	7	Strengthening very doubtful. Spark line of *Fe* at 4351.93
52.08	*Mg*	5 Nd?			
4352.91	*Fe*	4	7	9	Widened to red
53.04	*V*	0			
4355.26	*Ca?*	2	3	9	Perhaps winged
4356.06	—	0	2	9	Strengthening due mainly to violet component. Hasselberg gives *V* 4356.10
56.16	*Ni*	0			

TABLE II—*Continued*

A	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4356.53	—	0	∞	4	
4356.77	—	0	0–1	6	Widened to red
4359.65	*Ni*	0			
59.78	*Cr*	3	5	4	Spark line of *Zr*
59.91	*Zr*	0			
4360.45	—	1	0–1	4	
4360.64	*Ti*	1	1–2	7	
4362.91	—	0 N	∞	3	
4363.27	*Cr*	1 N	1–2	4	
4363.46	—	0 N	∞–0	4	Rowland's intensity too low: 1 better
4363.63	—	0	1–2	8	Very broad. Hasselberg gives *V* 4363.69
63.77	—	0			
4365.17	—	000	∞	3	
4366.06	*Fe*	2	2–3	3	
4367.22	—	000	0	3	Hasselberg gives *V* 4367.24
4367.75	*Fe*	5	6	8	Weak at red edge. Spark line of *Ti*
67.84	*Ti*	2			
4368.07	*Fe*	2	2–3	7	Narrow
4368.22	—	∞	0	3	Hasselberg gives *V* 4368.25
4369.05	*Ti*	∞ Nd?	0	3	
4369.57	—	1	0	6	
4371.14	*Zr*	1	1–2	7	Spark line of *Zr*
71.22	—	1			
4371.44	*Cr*	2	3–4	7	
4372.50	—	0 d?	0–1	7	Very broad. Hasselberg gives *Ti* 4372.54
4372.90	—	0	0	6	
73.01	—	0			
4373.42	*Cr*	1	2–3	7	Hasselberg gives *V* 4373.40
4373.73	*Fe*	2	1–2	5	Narrow
4374.98	*Zr*	0	3–4	4	
75.10	*V, Mn*	2			
4375.73	—	0	0	5	
75.82	—	0			
4376.11	*Fe*	6	8	6	Probably winged
4377.39	—	2 N	1–2	6	
77.53	—	0 d?			
4378.42	—	2 Nd?	1–2	5	
4379.40	*V*	4	7	6	Very broad
4380.32	*Co*	2 Nd?	1	6	
4380.88	—	2 Nd?	1	5	Broad
4381.27	*Cr*	0	0–1	5	Hazy, broad
4382.85	*Mn*	0	1–2	6	
82.93	—, *Fe*	2			
4384.48	—	1	0	4	
4384.87	*V*	3	4–5	6	Much widened
4385.14	*Cr*	2	3	6	
4385.55	—	2	0–1	5	Spark line of *Fe*
4387.01	*Ti?*	1	0	7	Spark line of *Ti*
4387.22	—	1 N	0	6	Possibly spark line of *Pb*
4388.06	*Fe, Co*	2	2–3	4	Widened

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4388.89	—	0	0	3	
89.03	—	0N			
4389.41	*Fe*, —	2	3	6	
4390.15	*V*	2	4	7	
4391.12	*Fe*	2	2–3	3	Weak on red edge. Spark line of *Ti*
91.19	*Ti*	1			
4391.82	*Co*	0			
91.92	*Cr*	1	3	7	Weak on violet edge
92.03	*Co*	0			
4392.24	*V?*	1 N	1–2	7	
4393.44	—	0	1	7	
4393.69	—	1 Nd?	0	5	
4393.97	*V?*	0	1–2	6	
94.09	*Ti*	0			
4394.22	*Ti?*	2	1–2	5	Narrow
4394.94	—	00	0–1	3	Hasselberg gives *V* 4394.98
95.02	*Zr*	00			
4395.20	*Ti*	3	2–3	7	Narrow. Spark line of *Ti*
4395.41	*V*, *Zr*	2	3	7	
4396.01	*Ti*	1	0–1	6	Spark line of *Ti*
4397.12	—	1 N	0–1	4	
4399.94	*Ti*, *Cr*	3	2–3	6	Spark line of *Ti*
4400.56	*Sc*	3	3–4	6	
4400.74	*V*	1	3	7	
4401.18	—	1 N	0–1	4	Possibly spark line of *Pb*
4403.35	—	1	0–1	6	
4404.43	*Ti*	1 N	1–2	4	
4404.93	*Fe*	10	9	6	Apparently narrowed in spot
4406.81	*V*, —	2	4	7	
4407.81	*V*	2	8	7	
07.87	*Fe*	4			
4408.36	*V*	2	3–4	7	
4408.58	*Fe*	3	7	7	Very broad
08.68	*V*	2			
4409.41	—	0	00	5	Widened to red
4409.68	—	1	0–1	4	
4410.68	*Ni*	2	1–2	3	
4411.24	*Cr* —	1	1–2	3	Widened. Spark line of *Ti* falls here.
4412.09	—	1	0	6	
4412.30	*V*	00	2	6	Hazy
12.42	*Cr*	0			
4413.76	—	1	0	6	
4415.29	*Fe*	8	7	4	Apparently narrowed in spot
4415.72	—	3	2–3	6	Narrow
4416.64	*V*	0	2–3	7	
4416.98	—	2	1	6	Narrow
4417.45	*Ti*	0	1–2	7	Broad
17.58	*Co*	00			
4417.88	*Ti*, —	3	2–3	6	Spark line of *Ti*
4418.50	*Ti*, —	1	0–1	5	Greatly widened. Rowland's intensity too low: 2 better

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4419.94	*Mn*	∞ N	1–2	7	Widened to red
20.10	*V*	∞ N			
4420.45	—	0	∞	6	
4421.73	*V*	0	2–3	7	Very broad
4421.93	*Ti*	∞	0	3	Perhaps spark line of *Ti*
4422.10	—	1	∞–0	6	
4422.98	*Ti*	0	1	7	
4423.30	*Fe*	1	2	7	Broad. Hasselberg gives *V* 4423.32 and *V* 4423.41
23.43	*Cr*	0 N			
4424.01	*Fe?*—	2	1–2	3	Narrow
4424.46	*Cr*	0	1–2	6	Hasselberg gives *Ti* 4424.58
24.53	—	∞			
4425.61	*Ca*	4	5–6	7	Winged
4426.20	*Ti*	0 Nd?	2	7	
4427.27	*Ti*	2	3	7	
4427.48	*Fe*	5	7	6	Winged
4428.71	*V–Cr*	1 d?	2	7	
4429.96	*V*	∞	1	7	
4430.36	*Fe*	1	0	7	
4430.52	—	∞	∞–0	3	
4430.78	*Fe*	3	3–4	3	
4431.30	—	0 N	∞	5	
4431.52	—	0	0–1	6	Hasselberg gives *Ti* 4431.46
4432.74	*Fe*	1	1–2	4	
4434.17	*Ti*	0 Nd?	1–2	7	
4435.13	*Ca*	5	7	7	Winged
4435.32	*Fe*	2	3	5	
4435.85	*Ca*	4	6	6	Winged
4436.31	*V*	0	1–2	7	
4436.75	—	∞	0	6	Hasselberg gives *Ti* 4436.75
4437.11	*Fe–Ni*	2 d?	1–2	4	Narrow
4437.73	—	0	∞	6	
4438.01	*V*	0	2	7	
4438.51	*Fe*	1	1–2	4	Very much widened
4440.05	*Fe*	1	2	4	Narrow
4440.52	*Ti*	∞	1	6	
4440.99	—	1	0–1	6	
4441.15	*Fe*	0	0	6	
41.26	—	0			
4441.43	*Ti*	∞	0	6	
4441.88	*V*, —	3 Nd?	5	7	Very broad
4443.00	*Fe*	1	1–2	6	Narrow
4443.98	*Ti*	5	4	7	Spark line of *Ti*
4444.38	—	0	2–3	7	Rowland's identification *V–Ti* for 4444.57 evidently belongs to this line. Hasselberg gives both *V* and *Ti* here
4444.73	*Fe, Ti*	2	1–2	6	
4445.64	*Fe*	1	2	7	
4447.30	*Mn, Fe*	2	2–3	4	
4447.89	*Fe*	6	8	6	Winged
4449.31	*Ti*	2	3	7	

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4450.65	*Ti?*	2	1–2	6	Narrow. Spark line of *Ti*
4451.09	*Ti*	1	2	6	
4452.17	*V*	0 N	2	7	
4453.17	*Mn*	1	1–2	3	
4453.49	*Ti*	2	3	7	
4453.88	*Ti*	1	2	6	
4454.55	*Fe*	3	3–4	4	
4454.95	*Ca, Zr*	5	7	6	Winged
4455.48	*Mn, Ti*	2	3	6	
4455.98	*Mn*	2	7	7	Winged
56.06	*Ca*	3			
4456.79	*Ca*	2	3–4	7	Perhaps winged
4457.60	*Ti, V, Zr*	2	5–6	6	Strengthened to violet
57.71	*Mn*	2			
4458.24	*Fe?*	2	1–2	6	
4459.52	*Cr*	1	1–2	4	Widened
4459.92	*V*	1	2–3	7	
4460.39	*V*	0	4	7	Rowland's intensity too low: 3 better for total
60.46	*Mn*	1			
60.52	—	0			
4461.82	*Fe*	4	6	6	Much widened
4462.16	*Fe–Mn*	3 Nd?	3–4	7	Widened
4463.57	*Ti–Ni*	0	2	6	Widened to red
63.70	—	00			
63.84	*Ti*	0000			
4464.62	*Ti?*	2	1–2	6	Narrow. Spark line of *Ti*
4464.84	*Mn*	2	3–4	3	
64.94	*Fe*	1			
4465.98	*Ti*	1	2	7	Rowland's intensity too high: 0 better
4466.73	*Fe*	5	6	6	Widened, hazy
4468.66	*Ti,* —	5	4–5	7	Spark line of *Ti*
4469.32	*Ti*	1	0–1	6	
4469.54	*Fe*	4	4	4	Narrow, probably winged
4469.87	*V*	00	0	7	
4470.30	*Mn*	1	1–2	6	
4471.41	*Ti*	0	2	7	
4471.72	—	00 N	1–2	7	Very broad
71.85	—	0			
71.97	—	00			
4472.88	*Fe*	1	2	4	Widened to red. Rowland's intensity too low: 2 better for total
72.97	*Mn*	0			
4473.10	*Ni?*	0	00	6	
4474.21	—	00	0	4	Hasselberg gives *V* 4474.21
4475.03	*Ti*	0	2–3	7	
4475.47	*Cr*	00	0	6	
4476.18	*Fe*	4	8	4	Perhaps winged
76.25	*Ag*	3			
4477.23	—	00	0	3	
4478.19	—	0	0–1	3	
4479.78	*Fe*	1	2	6	Widened to red
79.88	*Ti*	00			

TABLE II—*Continued*

λ	Element	Intensity Rowland	Intensity Spot	Number of Observations	Remarks
4480.31	*Fe*	1	2	6	
4480.75	*Ti, Ni*	0 N	0–1	6	
4480.99	—	0	00–0	3	
4481.30	—	0	000	6	Nearly obliterated. Rowland's intensity too low: 1 better
4481.44	*Ti*	1	2	6	
81.52	—	0			
4482.34	*Fe,—*	5	11	6	Much widened
82.44	*Fe*	3			
4482.90	*Ti–Fe*	1	2–3	6	Very hazy
83.04	*Cr*	00			
4484.39	*Fe*	4	4–5	3	
4488.22	*Fe–Cr*	0	2	6	Widened to violet
88.30	—	1			
4488.49	—	1	0	7	Spark line of *Ti*
4488.93	*V*	0000	2	7	Widened to violet
89.08	*Fe*	1			
4489.26	*Ti*	0	3	6	Widened to violet. Spark line of *Fe* at 4489.35
89.35	—	2			
4489.91	*Fe*	4	6	6	
4490.25	*Mn–Fe*	3 N	3–4	6	
4491.57	—	2	0–1	6	Spark line of *Fe*
4491.82	*Cr–Mn*	0	0–1	6	Rowland's intensity too high: 00 better
4492.48	*Cr, Fe*	0	0–1	6	Much widened
4493.70	—	1	0–1	6	Fringe on red side
4494.22	—	1	1–2	6	Much widened
4494.74	*Fe*	6	7–8	6	
4495.18	*Ti*	00	0	6	
4496.32	*Ti*	1	2–3	7	
4497.02	*Cr*	3	4–5	6	Hasselberg gives *V* 4497.03
4497.84	*Ti*	0 N	1–2	7	
4498.90	*Cr*	0	0–1	6	Rowland's intensity too high: 00 better
4499.07	*Mn*	1	1–2	6	Rowland's intensity too low: 2 better
4499.31	—	1	0–1	6	

MOUNT WILSON, CAL.
November 1907

SUN-SPOT BANDS WHICH APPEAR IN THE SPECTRUM OF A CALCIUM ARC BURNING IN THE PRESENCE OF HYDROGEN[1]

By CHARLES M. OLMSTED

In a recent paper by Hale and Adams,[2] it is shown conclusively that numerous flutings which appear in the spectrum of the flame of a titanium arc are present in the spectrum of sun-spots, the flutings with strong heads degraded toward the red at λ 7054.6, λ 7088.0, and λ 7125.9, being especially noticeable. Recently Fowler[3] has called attention to the coincidence of spot bands near the *b* group with the bands of magnesium hydride. Although titanium and magnesium hydride account for many of the band regions in spots, there are, nevertheless, many bands left unidentified. While examining the spectra of various compounds, and of metals under various conditions, in the hope of identifying more of these regions, a band spectrum of calcium burning in the presence of hydrogen was found. This band spectrum, which so far as I know has not been previously noticed, has without doubt its counterpart in the spectra of spots.

There are two main groups of bands: The stronger one at about λ 6385 (Plate VI); the fainter running through the B group. The bands are degraded toward the violet and are built up of rather complexly mixed series of lines. They are similar in appearance to the magnesium hydride bands, and, under low dispersion, present sharply defined heads on the side of greater wave-lengths. The group at λ 6385 has two strong heads (λ 6382.2, λ 6389.3) with less definite and fainter subheads on the red side of these. Heads at approximately λ 6393.0, λ 6398.5, and λ 6407.5 may be noticed.

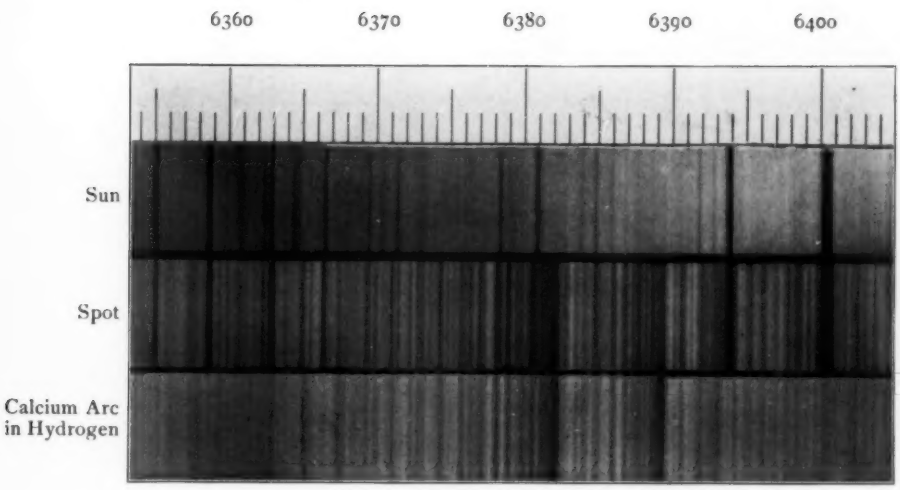
The band group in the B region, although strong and easily photographed when low dispersion is used, is, however, so weak under high dispersion that I have not succeeded as yet in getting a photo-

[1] *Contributions from the Solar Observatory*, No. 21.

[2] "Second Paper on the Cause of the Characteristic Phenomena of Sun-Spot Spectra," *Contributions from the Solar Observatory*, No. 15, *Astrophysical Journal*, **25**, 75–95, 1907.

[3] "The Origin of Certain Bands in the Spectra of Sun-Spots," *Monthly Notices*, **67**, 530–534, 1907.

PLATE VI



ORANGE BANDS COMMON TO THE SPECTRUM OF SUN-SPOTS AND TO THE CALCIUM ARC BURNING IN HYDROGEN

graph satisfactory for a detailed comparison with the spot spectrum. It should be remarked however, that a very much enlarged copy of a negative taken with an instrument of moderate dispersion (a heavy flint 60°-prism used in a Littrow spectrograph of twelve feet (366 cm) focal length) shows beyond a doubt that this group also is in spots. The structure of these bands is in some ways very similar to the group at λ 6385. The discussion of this point is reserved until a stronger high-dispersion photograph is obtained.

It seems very probable from the following facts that the spectrum under consideration is due to some compound of calcium and hydrogen:

The bands appear when an arc formed between metallic calcium electrodes burns either in commercial hydrogen or in hydrogen formed from zinc and hydrochloric acid and dried with sulphuric acid; but do not seem to appear when the same electrodes form arc in air.

Also these bands do not appear when dry calcium carbide is used as electrodes in air; but do appear if wet cotton surrounds the electrodes.

The bands appear when calcium metal electrodes are burned in air if a stream of steam or hydrogen enters the arc through a hole bored in one electrode.

The spectrum from which Plate VI was made was obtained by burning a calcium arc of from five to twenty amperes in an atmosphere of commercial hydrogen at atmospheric pressure. The arc was formed between a stationary copper rod as negative electrode and a rotating calcium disk as positive electrode. The first-order spectrum of a Littrow spectrograph of eighteen feet (549 cm) focal length with a six-inch (15.24 cm) grating of 14,438 lines to the inch (5684 lines to the cm) was used. With a slit width of 0.003 inch (0.075 mm) a net exposure of two hours with a Wrattan & Wainwright panchromatic plate was necessary.

It should be mentioned that while testing calcium carbide in air to see if the spectrum were due to the carbide, some bands in the green, due to calcium carbide, were noted. These are beautiful strong bands degraded toward the red; but as they do not appear in spots, their discussion does not belong to this communication.

The following table of wave-lengths indicates the agreement which exists between the individual lines of the bands of the spectrum

Sun-Spot		*Ca* in H_δ		Notes	
λ	Int.	λ	Int.	Spot	*Ca* in H_δ
6369.45	6	.39	6	Center of wide blend	Center of wide blend
70.16	4	.10	4	Maximum of wide blend	Maximum of wide blend
70.55	1				
70.80	1	.76	1		Double
71.14	10	.16	8		
71.57	5	.63	1		
72.37	6	.37	5		
72.88	5	.89	5	*Ti* line at 72.86	
73.23	5	.23	4		
73.67	2	.66	1	Wide	Double
74.03	1	.02	1	Double	Double
74.42	14	.42	10		
74.94	2	.99	2		
75.29	2	.31	1		
75.80	6	.80	8		Wide
76.07	2				
76.47	6	.46	4		
76.64	1	.62	1		
77.08	8	.17	5	Wide	Wide
77.39	4			Hazy *Ti* line at 77.27	
78.18	12	.15	12	Double	Double
78.48	2				
79.00	16	.00	10	Wide	Wide
79.57	3	.60	1	*Ti* line at 79.54	
79.93	4	.93	7		
80.23	2				
80.62	10	.62	8	Blurred triplet	Wide
80.97	6			Double	
81.26	8	.26	8		
81.61	8	.65	5		Double
81.96	6	82.02	6		
82.21	16	.25	20		
		82.41	2		
		82.62	1		
82.81	3	.79	2		
82.98	1				
83.38	1				
83.57	2	.56	2	Double	Double
84.02	4	83.97	4		
84.31	4	.31	4		
84.91	9	.91	6	Wide (triplet)	Wide
85.60	3	.57	2		
86.04	12	.04	11	Wide	Wide
86.91	9	.95	8	Maximum measured—has violet wing	
87.31	4	.35	2		
87.68	5	.63	4	*Ti* line at 87.70	
87.84	5	.86	3		
87.91	3	.92	3		
88.71	6	.67	6	Maximum	Maximum
89.02	2	88.98	2	*Ti* line at 88.99	
89.34	16	.33	20	Double	Double
89.79	1				
90.05	2	.00	1		

Sun-Spot		*Ca* in H_δ		Notes	
λ	Int.	λ	Int.	Spot	*Ca* in H_δ
6390.17	4	.19	4		
90.68	10	.68	10	*Ti* line at 90.65	Wide
91.26	4				
91.68	2	.68	2		
91.94	6	.93	6	*Ti* line at 92.03	
92.35	2	.35	2		
92.61	1				
92.75	3	.80	1		
93.18	4	.18	5	[*Fe* 7	
93.81	50	.80	2	Solar line at 6393.820	
94.48	6	.48	6		
95.00	4	.02	4	*Ti* line at 94.93	
95.31	6	.32	4		
96.03	4				
		96.16	1		
96.25	5	.26	5		
96.58	1	.58	2		
		96.78	1		
96.89	4				
97.07	4	.05	4		
97.58	2				
97.66	6	.68	6		
98.45	9	.44	6	Double	Double
98.49	5	.48	4		
		99.33	2		
99.70	4	.65	3		
		99.84	1		
6400.22	60			Solar line 6400.217 *Fe* 8	
		00.27	6		
00.56	40	.59	2	Solar line 6400.538 *Fe* 2	
01.09	2	.15	2	Wide	Wide
01.56	6			Wide: *Ti* line at 01.48	
02.03	4	.04	4		
02.34	4				
02.49	6	.48	8		
02.94	4	.98	4		
03.58	6	.50	4	*Ti* line at 03.56	
04.32	2	.37	2	Double	Wide

of the calcium arc burning in hydrogen and those of the sun-spot spectrum. The scale of intensities is purely arbitrary, the larger numbers indicating greater intensities. Out of eighty-four spot lines (all that could be distinctly seen between λ 6389 and λ 6405) sixty-two are matched to within 0.05 tenth-meters by band lines of *Ca* in hydrogen. Within this same region there are twelve lines of the calcium spectrum which are not matched to within 0.05 tenth-meters by spot-lines. Probably five of these disagreements are due to errors of measurement greater than 0.05 tenth-meters, the remainder to impurities.

Mount Wilson
November 1907

WAVE-LENGTHS OF TITANIUM λλ 3900 AND 3913 IN ARC AND SPARK

By NORTON A. KENT and ALFRED H. AVERY

In June 1905 one of us (Kent) published the results of a careful series of experiments dealing with the variation in wave-length of certain lines of the spark-spectra of titanium, iron, and zinc with the electrical conditions of the discharge.[1] Subsequently Keller, working under Kayser, published a paper[2] in which the suggestion was made that the apparent non-coincidences of the spark and the comparison arc lines were due to the fact that the slit was not accurately adjusted to parallelism with the grating ruling; and the statement was made that the plumb-line method of adjustment employed by the writer was of less delicacy than the spectroscopic.

FIG. 1.—AA', direction of grating ruling; EE', direction of slit; LL', direction of resultant line.

The substance of Keller's explanation of the manner in which shifts could be introduced by orientation of the spectrometer slit is as follows: Given a perpendicular grating ruling, an astigmatic instrument such as the concave grating will give a perpendicular line image for every point of the line source as object. If, then, this line source or slit be at an angle (say clockwise as one faces it) with the grating ruling, the spectral line will be a composite of lines arranged as in Fig. 1.

The result will be an image which is apparently rotated in the direction of the slit. If, then, on one photographic plate two exposures be made, one each of arc and spark, and the position of the adjacent tips of the images of any spectral line be measured by a comparator, any displacement desired may be introduced by a rotation of the slit.

But Keller's explanation does not apply to the method of exposure

[1] *Proceedings of the American Academy of Arts and Sciences*, 41, No. 10, July 1905.

[2] *Ueber die angebliche Verschiebung der Funkenlinien*, Inaugural-Dissertation, 1906.

employed by Kent—a method of triple exposure, two of the arc (the first and the third) superimposed horizontally but not wholly vertically and spanned by the spark exposure.

It is difficult to see how non-parallelism of slit and ruling could in this case introduce a shift. Keller seems to have overlooked the fact that this triple method was employed, for no mention is made of it in his paper. However, despite the fact that it was not apparent how the above-mentioned criticism could apply, it seemed advisable to test the matter, and the following experiments were undertaken to decide the two following questions:

1. Is the plumb-line method of adjustment of slit and grating ruling to parallelism more or less accurate than the spectroscopic?

2. Will an orientation of the slit introduce a shift if the triple method of exposure be used?

CONDITIONS OF EXPERIMENT

The conditions under which the present work was carried on were, as far as possible, those of the previous series of experiments. By the courtesy of Professors Trowbridge and Sabine every facility of the Jefferson Physical Laboratory was placed at our disposal. The 6-inch Rowland concave grating—with 20,000 lines to the inch and 21 feet radius of curvature, an excellent instrument—was kindly loaned by Professor Trowbridge, and the mount was that belonging to the laboratory and located on the third story of the building. The beams were heavy timbers supported wholly from the wall. The slit, grating-holder, camera-box, rheostat, transformer, and condenser were those used in the former work. The usual precautions relative to temperature changes were taken, the whole mount being wrapped in several layers of newspaper. The vibrations of the building due to wind and heavy machinery necessitated working at times when these disturbing influences were absent. All plates which did not show horizontal coincidence of the arc exposures were rejected. The current used for both arc and spark was the 110-volt, 66-cycle, alternating current of the Cambridge Electric Light Company. The frequency of the current used in the previous work was 133, but as the transformer was built for 66 cycles no difficulty was experienced in this regard. The voltmeter, ammeter, and wattmeter were of

Thompson form and of ranges, 0–65 volts; 0–60 amperes; 0–45 hecto-watts, respectively. Thus the conditions were the same as those formerly employed in all respects except location, frequency of current, and grating.

RESULTS OBTAINED

1. *Relative merits of plumb-line and spectroscopic methods of adjustment.*—The grating-holder was fitted with two opposing screws moving in a horizontal plane and controlling the orientation of the grating. It was found by trial that by the unaided eye the parallelism of either end of the ruled space of the grating with the silk thread of a plumb-line suspended from the grating-holder could be adjusted so that the separate settings made by each of us agreed to within 45° on the head of one of the screws. This means that the grating can be set by plumb-line to within 3.3 minutes of arc.

Opening the slit and hanging the bob so that the thread could be seen through it, the various settings made by each of us agreed to 10° on a divided head fitted to the tangent screw. This means by calculation 1.7 minutes of arc of rotation of the slit.

On the other hand, using full length of slit as in the previous case and appropriate width, about $\frac{1}{1000}$ inch, various exposures of the arc were taken on the same plate in the manner customary in making focus plates except that the camera-box was left clamped and the slit was oriented. These plates showed no difference in the spectra when the scale on the divided head of the tangent screw was rotated 90° clockwise or counter-clockwise from the position of parallelism as determined by plumb-line, making a change of 15.3 minutes in the orientation of the slit—a change nine times as great as that in the case of the plumb-line. However, the relative merits of the two methods must not be taken as nine to one, but merely as about four to one, for the plumb-line adjustment for the grating is only about one-half as accurate as that for the slit.

The above facts make it extremely probable that the adjustment of the slit in the previous investigation was good. And, further, if with full length of slit no change in definition could be detected for a rotation of 90°, it is all the more probable that with a slit of 5 mm in length, as used in making regular exposures, the definition was the best obtainable.

2. Further, as to *shift as a function of orientation of the slit*, a series of plates was taken with the slit oriented approximately 1° and 0°.5 clockwise and counter-clockwise, including a series at parallelism or 360° and 180° counter-clockwise, 0°, and 180° and 360° clockwise on the divided head. If orientation introduce shift, the shift-orientation curve should either show a point of inflection at zero orientation or cross the displacement axis at that point. Tables I and II are self-explanatory. The data therein given show that for the two lines studied neither of the above possibilities is realized. The shift is not influenced by the orientation of the slit but is, within the limits of error of the experiment, constant at all orientations investigated.

The agreement between the means obtained formerly by Kent and those given in the present investigation is as close as could be expected.

Particulars of Table I

Metal used; Titanium Carbide, 85 per cent. *Ti.*, 15 per cent. *C.*
Arc vertical; length 3 mm; spark horizontal; length 9 mm.
End of spark image always used.
Capacity of condenser, 0.0226 microfarads.
Times of exposures, arc, 5+5 seconds; spark, 75 seconds.
Plates, Seed, Gilt Edge, No. 27.
Developer, metol, adurol, hydrochinon.
Second order spectrum.
Width of slit, 0.025 to 0.050 mm; length, 5 mm.
Length of grating lines used, 14 mm.

TABLE I

SHIFT OF SPARK LINES TOWARD RED FROM POSITION OF ARC LINES
ORIENTATION OF SLIT, CLOCKWISE 360°

PLATE NO.	AMPERES	VOLTS	WATTS	SHIFT IN TENTH-METERS			
				λ 3900.68		λ 3913.58	
				Kent	Avery	Kent	Avery
19.....	....	....	...	0.035	0.041	0.030	0.035
20.....	....	....	...	21	31	18	28
52.....	39.0	19.0	...	32	42	31	26
54.....	40.0	18.8	...	16	23	16	20
88.....	41.0	16.0	450	25	21	18	12
89.....	40.5	16.0	450	18	26	21	23
122.....	41.3	19.0	500	14	14	12	12
123.....	41.3	17.0	500	13	12	12	16
124.....	41.5	17.0	500	11	10	7	14

TABLE I—*Continued*

CLOCKWISE 180°

PLATE NO.	AMPERES	VOLTS	WATTS	SHIFT IN TENTH-METERS			
				λ 3900.68		λ 3913.58	
				Kent	Avery	Kent	Avery
35.....	40.0	16.5	...	0.020	0.027	0.026	0.022
36.....	40.0	16.5	...	12	22	10	19
49.....	40.0	18.0	...	15	20	18	17
51.....	39.3	18.0	...	14	13	15	15
85.....	40.5	17.0	490	20	18	19	24
87.....	41.0	16.5	450	20	21	16	20
119.....	41.5	19.5	520	15	18	16	25
120.....	42.0	17.5	480	13	22	13	18
PARALLEL, OR 0°							
32.....	38.5	19.0	...	0.019	0.023	0.015	0.017
39.....	39.0	21.0	...	27	28	23	24
40.....	40.5	17.0	...	7	13	4	12
44.....	39.8	19.0	...	29	30	29	33
45.....	40.0	19.0	...	25	21	21	29
48.....	37.5	21.5	...	18	18	14	17
63.....	41.0	16.0	500	14	18	16	17
68.....	39.0	19.0	500	8	10	5	5
72.....	40.0	17.5	490	23	23	23	25
74.....	39.5	17.5	450	39	29	42	34
COUNTER-CLOCKWISE 180°							
76.....	40.0	22.0	500	0.025	0.019	0.024	0.029
77.....	40.0	19.0	450	16	10	16	8
78.....	40.0	19.0	450	32	42	32	27
83.....	41.0	15.0	450	25	26	20	18
101.....	40.0	17.0	450	8	12	6	19
102.....	39.0	19.0	450	11	9	14	14
116.....	41.0	19.0	550	14	19	13	10
117.....	41.8	18.5	550	18	16	15	10
COUNTER-CLOCKWISE 360°							
21.....	....	....	...	0.012	0.012	0.014	0.013
22.....	....	....	...	29	34	27	40
23.....	40.8	15.5	...	10	23	11	13
26.....	42.0	15.5	...	6	20	8	16
58.....	40.0	19.3	...	12	16	15	15
82.....	40.0	19.0	500	28	23	24	22
110.....	41.0	19.0	450	12	7	12	9
112.....	42.5	15.0	450	15	9	14	12
114.....	41.0	15.5	450	14	11	13	14

TABLE II

SUMMARY OF TABLE I

λ 3900.68

		Clockwise		0°	Counter-Clockwise	
Orientation		360°	180°		180°	360°
Means	Kent	0.021	0.016	0.021	0.019	0.015
	Avery	24	20	21	19	17

λ 3913.58

Means	Kent	0.018	0.017	0.019	0.018	0.015
	Avery	21	20	21	17	17

	λ 3900.68		λ 3913.58	
	Kent	Avery	Kent	Avery
Means of Means at All Orientations	0.018	0.020	0.017	0.019
Weighted means of all measurements	0.019		0.018	
Weighted means at parallelism	21		20	
Means as given by previous investigation under similar conditions	19		18	

The average deviation from the mean of two measurements (of the shift of a line) on any one plate is 0.003 (Kent) and 0.004 (Avery) t.-m. for λ 3900.68; and 0.002 (Kent) and 0.003 (Avery) t.-m. for λ 3913.58. It will be noticed that the value of the shift given on the different plates varies considerably. This is probably due to the fact that it was difficult to set the very end of the spark image accurately upon the slit. As shown in the previous paper the part of the image employed influences the character of the line and the value of the shift.

During the progress of the work it was suggested to us that the use of the tip of the spark line as that part of the line upon which to set the thread of the microscope in measuring was perhaps objectionable owing to the fact that there might be a shift due to diffraction resulting from reducing the virtual aperture of the grating by strips of black paper set only *roughly* perpendicular to the ruling, the measurement being made by a mm scale. Three exposures on one

plate were therefore made—all of the arc, and the first and third superimposed as usual. No shift was shown when the slit was either parallel or oriented as indicated in Table III.

TABLE III

ARC AND ARC

PLATE NO.	ORIENTATION OF SLIT							
	λ 3900.68				λ 3913.58			
	Parallel, or 0°		Counter-clockwise 360°		Parallel, or 0°		Counter-clockwise 360°	
	Kent	Avery	Kent	Avery	Kent	Avery	Kent	Avery
106....	−0.001	0.003			−0.002	0.002		
107....	1	2			4	3		
109....			2	5			3	2

At the end of the series of experiments the water rheostat was cut out of the transformer circuit and in its place was inserted a choke coil of closed magnetic circuit of U-form with adjustable armature. When adjusted roughly to show maximum power as measured by the wattmeter, with a spark length as indicated in Table IV, the shift was increased to 0.032 t.-m. in the mean for λ 3900.68 and 0.033 t.-m. for λ 3913.58.[1]

TABLE IV

(Conditions same as in Table 1, except spark length = 9 mm in Plate 125 and 15 mm in Plates 126 to 128. Time of exposures for spark = 60 seconds.)

PLATE NO.	CONDITIONS OF PRIMARY CIRCUIT			ORIENTATION OF SLIT: PARALLEL, OR 0°			
				λ 3900.68		λ 3913.58	
	Amperes	Volts	Watts	Kent	Avery	Kent	Avery
125.....	50	28	1,000	0.040	0.038	0.031	0.040
126.....	49	27	950	33	33	30	49
127.....	50	24	800	30	30	32	29
128.....	50	26	800	26	29	22	31
Means...				32	32	29	37

[1] At the request of the writer Mr. Walter S. Adams of the Carnegie Solar Observatory kindly measured Plate No. 126 upon one of the Observatory comparators and obtained values of 0.040 and 0.038 for λλ 3900 and 3913 respectively.

It is the purpose of the writer of the former paper to study with an echelon the position of the narrow and less diffuse lines of the titanium spectrum.

In conclusion we wish to acknowledge the kindness shown us by Professor Trowbridge and those associated with him in so generously putting at our disposal all the facilities of the Jefferson Physical Laboratory; and our thanks are due also to the Rumford Committee for the grant made in aid of this research.

DEPARTMENT OF PHYSICS
Boston University
November 1907

THE LARGE PROMINENCE OF MAY 21, 1907

By J. FÉNYI

In the October number of this *Journal* (**26**, 155, 1907) Mr. Fox contributed a paper, illustrated with four photographs, on this phenomenon, somewhat unusual at our present very feeble maximum. As this eruptive prominence was observed, sketched, and measured at precisely the same time in Kalocsa, it will be of interest to compare these visual observations with the photographic results.

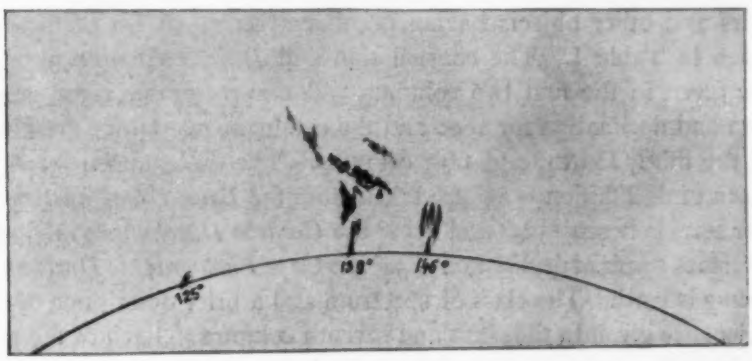
Having seen the prominence on his first exposure, Fox began at $4^h\ 52^m$ G. M. T. to take photographs of it in rapid succession. At the same time I had just completed the sketch of the prominence and began to measure its height by means of transits across the slit. The time of the first transit was not noted, but it can be deduced from the data after the seventh transit, and is put at $4^h\ 52^m$—that is, at the very moment when Fox made his second exposure. I observed successively eleven transits concluding at $5^h\ 3^m$. The eighth transit at $5^h\ 0^m$ coincides roughly with Fox's third exposure. The observed heights follow:

G. M. T.	Photographic	Visual	Ph.—V.
$4^h\ 52^m$.....	259″	190″	69″
5 02	280	226	54

The visual spectroscopic observations give lower altitudes than the photographic. The atmospheric conditions in Kalocsa were unfavorable, as also at the Yerkes Observatory. After $5^h\ 3^m$ the conditions were so bad that observations were given up. On the following day, nineteen hours later, with favorable atmospheric conditions, no prominence was visible at this position.

The accompanying sketch shows the form as drawn at Kalocsa only a few minutes before the first transit. This should therefore agree with Fox's photograph No. 2. We find, however, such differences that no part of them can be identified: for example, in Kalocsa a column was seen resting on the chromosphere, which is lacking in the photograph. The sketch on the whole much more strongly recalls No. 1, which, however, was exposed fifty minutes earlier.

The rapid ascent of the prominence was also observed in Kalocsa. The first seven transits considered successively reveal the ascension, which between $4^h\ 52^m$ and $5^h\ 0^m$ amounted to 36″, that is, at a rate of 54 km per second. The simultaneous exposures of Fox, Nos. 2 and 3, give only 30 km. The difference is considerable, but it can be ascribed to the uncertainty of my estimated time and to the indefiniteness of the object (the upper filaments were very weak), even aside from the fact that we did not measure strictly the same object, since a hydrogen prominence was observed visually while a calcium



Prominence as observed at Kalocsa, May 21, 1907; height, 226″

prominence was measured on the photographs. I must also remark that during the eleven transits, which covered twelve or fifteen minutes, no change of form was noticed: all the parts, as they are shown in the sketch, passed in the same relative position, successively across the slit.

I have never observed the subsidence of a prominence of great height, say of over 240″. Rapidly rising prominences have always as quickly dissipated themselves at great elevations, thus yielding a lower altitude. At less heights, somewhere under 60″, the subsidence is seen not seldom; for very small prominences of about 20″ altitude the descent is the usual occurrence. It would certainly be of the greatest importance for the theory of prominences if the subsidence of one that had reached great elevations might be proved photographically.

HAYNALD OBSERVATORY
Kalocsa, Hungary

Minor Contributions and Notes

STARS HAVING PECULIAR SPECTRA. FIFTEEN NEW VARIABLE STARS[1]

An examination of the photographs of the Henry Draper Memorial, by Mrs. Fleming, has led to the discovery of a number of variable stars and other objects having peculiar spectra. A list of these is given in Table I. The constellation and *Durchmusterung* number are given in the first two columns. The approximate right ascension and declination for 1900 and the catalogue magnitude are given in the third, fourth, and fifth columns. The designations for stars north of declination $-23°$ are taken from the *Bonn Durchmusterung*. For stars between $-23°$ and $-52°$ the *Cordoba Durchmusterung*, and for stars south of declination $-52°$ the *Cape Photographic Durchmusterung* is used. The class of spectrum and a brief description of the object are given in the sixth and seventh columns. Each of the new variables has been confirmed by Miss L. D. Wells, unless otherwise specified. Additional information regarding these objects is given in the Remarks following the table. In the case of new variable stars, the right ascension is followed by the designation, described in *H.A.*, **48**, 93, which gives the approximate position, and also the designation described in *H.A.*, **53**, 147, which indicates the number in the series of variables found at Harvard. This last number is also given in the table, for convenience of future reference.

The star $+66°780$ is given by Dunér and by Krüger as of the fourth type. It was announced as a variable in *H.C.*, 124. The spectrum appears to change on the photographs available for examination. On Plate I 3247, taken on March 5, 1891, the spectrum is faint but clearly shown and contains no bright line. On Plate I 12509, taken on March 14, 1895, the object is near the edge of the plate. No part of the continuous spectrum is visible, but the bright line $H\beta$ is well defined and easily seen. On Plate I 12724, taken on

[1] *Harvard College Observatory Circular*, No. 132.

April 19, 1895, the line $H\beta$ appears as a strong bright line, and the portion of the continuous spectrum shown is of shorter wave-length than $H\beta$, and does not extend beyond $H\gamma$. On Plate I 33878, taken on February 22, 1906, the line $H\beta$ appears as a strong bright line, and the brightest and best-defined portion of the spectrum is of greater wave-length than $H\beta$, but the portion between $H\beta$ and $H\gamma$ is also well shown, although about half a magnitude fainter than the part of greater wave-length than $H\beta$. On Plate I 34569, taken on March 7, 1907, the line $H\beta$ appears as a faint bright line, while the continuous spectrum is well shown and is similar to that on Plate I 33878. The object is difficult to describe on these plates, since all were taken with the 8-inch Draper Telescope using a small prism, and the portion visible on the individual plates amounts to 1.8, 0.1, 0.7, 1.6, and 1.8 millimeters, respectively. Plate I 10978, taken with the same telescope, using an 8° prism, shows a very faint spectrum which is similar to that on Plates I 33878 and I 34569.

TABLE I

PECULIAR SPECTRA

Constellation	B. D.	R. A. 1900	Dec. 1900	Mag.	Spectrum	Description
		h. m.	° ′			
Aries	+11°305	2 9.6	+11 46	8.9	Pec.	Variable?
Auriga	+45.1324	6 28.2	+45 43	8.7	Mc	Variable. H 2992
Monoceros	− 4.1708	6 48.3	− 4.27	9.0	Na	Variable. H 2993
Canis Major	−22.1850	7 19.4	−22 47	9.1	Na	Variable. H 2994
Cancer	+15.1808	8 16.8	+15 19	8.6	Mc 5 d	Variable. H 2995
Ursa Major	.....	9 44.4	+53 7	...	Pec.	Dark bands
Vela	−49.5234	10 21.0	−49 54	9.6	Pec.	Dark bands
Carina	−72.1048	10 48.7	−72 14	9.8	Mb 5 c	Variable. H 2996
Musca	R	11 35.0	−72 0	8.5	Na	Variable. H 2997
Virgo	.....	12 0.0	+12 56	...	Md	Variable. H 2998
Musca	R	12 17.4	−74 57	9.5	Na	Variable. H 2999
Corvus	−16.3503	12 32.3	−16 43	9.6	Mc 5 d	Variable. H 3000
Centaurus	−63.2720	13 15.5	−63 42	9.5	Na	Variable. H 3001
Centaurus	−56.5891	13 36.4	−56 16	6.8	Pec.	Class A, peculiar
Circinus	−67.2622	14 30.9	−67 46	7.0	Pec.	$H\beta$ bright
Corona Borealis	+39.2901	15 37.8	+38 53	7.0	Mc 5 d	Variable. H 3002
Draco	+57.1786	17 35.4	+57 48	9.3	Mc 5 d	Variable. H 3003
Ophiuchus	+ 6.3898	18 37.1	+ 6 43	9.0	Pec.	Dark bands
Aquila	.....	20 7.1	+11 35	...	Pec.	Bright line. Type V
Draco	+74. 861	20 25.9	+74 56	9.3	Mc 5 d	Variable. H 3004
Cygnus	+32.3850	20 27.6	+32 14	9.1	Na	Variable. H 3005
Pegasus	+34.4597	22 1.4	+34 52	8.5	Mc 5 d	Variable. H 3006
Aquarius	−21.6376	23 6.3	−21 32	9.0	Pec.	Dark bands

REMARKS

h m

2 9.6. An examination of twenty-four chart plates, taken between January 13, 1890, and September 6, 1905, shows a small but distinct variation in the light of this star. On several plates it is about 0.2 magnitude fainter than +11°303, mag. 9.5 (assumed photographic magnitude 8.6), while on others it is about 0.3 to 0.4 magnitude brighter than that star. Estimates from these plates gave the approximate limiting magnitudes, 8.2 to 8.8.

6 28.2. 062845 = H. V. 2992. An examination of this star on twenty-one chart plates, taken between March 3, 1890, and March 11, 1905, shows a variation of about 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 9.4.

6 48.3. 020911 = H. V. 2993. The spectrum of this star is already known as Type IV. An examination of sixteen chart plates of this object, taken between February 22, 1891, and November 11, 1904, shows a variation of about 1.2 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.2 to 10.4.

7 19.4. *071922* = H. V. 2994. An examination of this star on twenty-one chart plates, taken between April 17, 1894, and November 30, 1904, shows a decided although small variation of 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 11.0 to 11.9.

8 16.8. 081615 = H. V. 2995. An examination of this star on eighteen chart plates, taken between February 14, 1899, and January 30, 1906, shows a variation of about 0.9 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.4 to 10.3.

9 44.4. This spectrum is faint, but is apparently of the same type as *C.DM.* −47°6614, described in *H.C.* 76.

10 21.0. This spectrum is of the same type as *C.DM.* −47°6614, described in *H.C.* 76.

10 48.7. *104872* = H. V. 2996. An examination of this star on eighteen chart plates, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.8 to 11.5.

11 35.0. *113572* = H. V. 2997. This star is *A.G.C.* 15946 and is known to have a spectrum of Type IV. An examination of eighteen chart plates of this object, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.6 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.6 to 10.2.

12 0.0. 120012 = H. V. 2998. An examination of this star on fourteen chart plates, taken between April 25, 1891, and May 9, 1905, shows a variation of about 4.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 12.5.

12 17.4. *121774* = H. V. 2999. This star is *A.G.C.* 16865. An examination of sixteen chart plates of this object, taken between May 2, 1893, and March

29, 1905, shows a variation of about 1.8 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.8 to 10.6.

12 32.3. *123216*=H. V. 3000. An examination of this star on twenty chart plates, taken between April 1, 1890, and May 12, 1905, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.8 to 10.5.

13 15.5. *131563*=H. V. 3001. The spectrum of this star is already known as Type IV. An examination of eighteen chart plates of this object, taken between May 24, 1889, and January 30, 1901, shows a variation of about 1.5 mag. Estimates from these plates gave the approximate limiting magnitudes, 9.0 to 10.5.

13 36.4. On Plate B 5271, taken on May 25, 1890, the hydrogen lines are very faint and narrow in the spectrum of this star. On Plate B 36285, taken on June 24, 1905, the lines $H\beta$ and $H\gamma$ are bright on the edge of greater wave-length, while $H\delta$, $H\epsilon$, and $H\zeta$ appear as broad dark bands with narrow bright lines superposed toward the edge of shorter wave-length. These give the spectrum on this plate the appearance of being that of a spectroscopic binary.

14 30.9. On Plate B 36127, taken on May 27, 1905, $H\beta$ appears as a faint bright line.

15 37.8. 153738=H. V. 3002. An examination of this star on twenty-eight chart plates, taken between June 2, 1892, and February 11, 1907, shows a variation of about 1.3 mag. Estimates from these plates gave the approximate limiting magnitudes, 7.0 to 8.3.

17 35.4. 173557=H. V. 3003. Variability suspected by Espin. *A. N.*, **145**, 327. An examination of this star on twenty-one chart plates, taken between August 17, 1892, and October 10, 1902, shows a variation of about 1.7 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.0 to 9.7.

18 37.1. This spectrum is of the same type as *C.DM.*−47°6614, described in *H.C.*, 76.

20 7.1. Galactic longitude, 20° 45′. Galactic latitude, −13° 6′. In Heis's Atlas, Plate VII, in *Aquila*, in Plate XII, near border of *Delphinus*.

20 25.9. 202574=H. V. 3004. An examination of this star on nine chart plates, taken between October 18, 1894, and October 28, 1903, shows a variation of about 2.2 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.3 to 10.5.

20 27.6. 202732=H. V. 3005. An examination of this star on ten chart plates, taken between August 4, 1890, and November 9, 1905, shows a variation of about 1.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.5 to 9.5.

22 1.4. *220134*=H. V. 3006. An examination of this star on twenty chart plates, taken between December 22, 1890, and September 27, 1905, shows a

variation of about 1.0 mag. Estimates from these plates gave the approximate limiting magnitudes, 8.2 to 9.2. This object was found to be variable by Mrs. Fleming on November 26, 1904, but since the change was slight, about half a magnitude, on the plates examined, publication was withheld until the star was rediscovered independently by Miss Leavitt in her examination of the Harvard Maps of the Sky. She found a change of about 0.7 mag.

23 6.3. This star is announced as of Type IV in *Astronomy and Astrophysics*, **12**, 546. On Plate A 8155, taken with the 24-inch Bruce Telescope, on October 11, 1906, a good image of the spectrum of this star shows that it is of the same type as *C.DM.*−47°6614, described in *H.C.* 76.

EDWARD C. PICKERING

OCTOBER 15, 1907

CORRECTION TO MR. WALLACE'S ARTICLE IN THE DECEMBER NUMBER

In Mr. Wallace's article entitled "Studies in Sensitometry. II. Orthochromatism by Bathing," through an unfortunate blunder on the part of the printer, the final paragraph (p. 325) was allowed to stand, while it should have been omitted. The failure of the engravers properly to reproduce the author's illustrations made it necessary to omit the plate, which was at first intended to accompany the paper. The last four lines of the article, constituting the final paragraph, should therefore be stricken out.

The small plate on p. 300 is also a very unsatisfactory representation of the author's spectra, and the words "*Li* λ 6103" should be crossed off, as the engraving fails to show the line intended.

Also in footnote 2 on p. 304, for "battered plates" read "bathed plates."

EDITORS

OBITUARY NOTICE

We record with deep regret the recent decease of two eminent astrophysicists, chiefly distinguished for their researches in solar physics.

PIERRE JULES CÉSAR JANSSEN,

director of the Astrophysical Observatory, Meudon, died at Paris on December 23, 1907, in the eighty-fourth year of his age.

CHARLES AUGUSTUS YOUNG,

emeritus professor of astronomy in Princeton University, an editorial collaborator of this *Journal* since its foundation, died at Hanover, N. H., on January 3, 1908, at the age of seventy-three years.

Appropriate accounts of the lives and works of these scientists will appear later in the columns of this *Journal*.

NOTICE

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention is given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* shorter articles will generally be placed and subjects may be discussed which belong to other closely related fields of investigation.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with the red end on the right, unless the author requests that the reverse procedure be followed.

Accuracy in the proof is gained by having manuscripts type-written, provided the author carefully examines the sheets and eliminates any errors introduced by the stenographer. It is suggested that the author should retain a carbon or tissue copy of the manuscript, as it is generally necessary to keep the original manuscript at the editorial office until the article is printed.

All drawings should be carefully made with India ink on stiff paper, usually each on a separate sheet, on about double the scale of the engraving desired. Lettering of diagrams will be done in type around the margins of the cut where feasible. Otherwise printed letters should be put in lightly with pencil, to be later impressed with type at the editorial office, or should be pasted on the drawing where required.

Authors will please carefully follow the style of this *Journal* in regard to footnotes and references to journals and society publications.

Authors are particularly requested to employ uniformly the metric units of length and mass; the English equivalents may be added if desired.

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